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December 5^{th}, 2018

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Dear Dr. Paul Labossiere,

Enclosed is the team’s final design report submitted on Wednesday, December 5^{th}, 2018. The purpose of our report is to propose a design for fan inlet covers for the wind tunnel located at the GE TRDC. The report defines the problem with all the client needs, constraints, and specifications affecting the design. An overview of the design details key features for installation. This report also includes preliminary engineering drawings, a list of vendors for all sourced components, and a bill of materials for all parts. An installation manual provides detailed instructions on how to properly install and uninstall the covers.

We would like to acknowledge our advisor Kathryn for providing feedback throughout the design and Aidan for helping us to structure our reports. Please feel free to contact our team manager, Filip Kurlowicz at , with any questions, comments, or concerns you may have about our report.

Kind regards,

Eric Barnson

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MECH 4860 – Final Design Report

Design of Wind Tunnel Fan Cover for GE TRDC and WestCaRD

Prepared for: GE Aviation
WestCaRD
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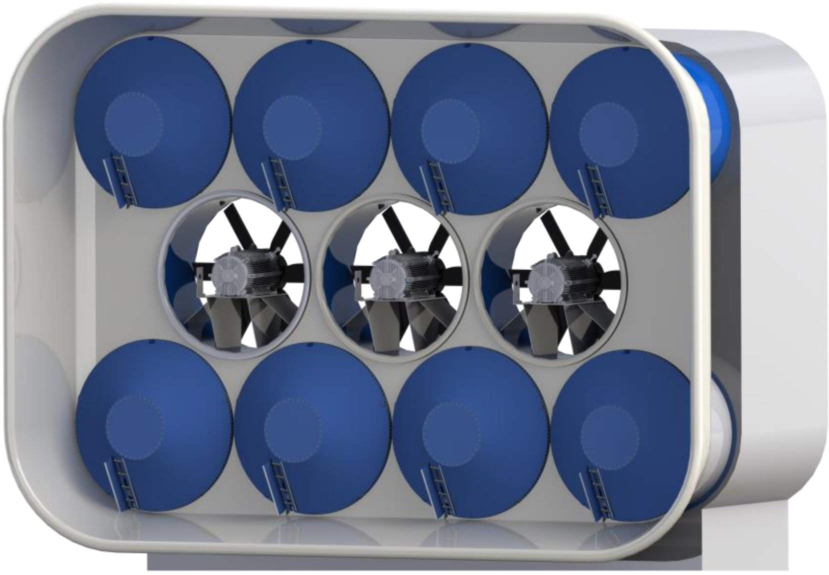
UNIVERSITY OF MANITOBA



Team: **16, General Mechanics Inc.**

Date: **December 5th, 2018**

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Executive Summary

The General Electric Engine Testing, Research and Development Center is operated by StandardAero and West Canitest R&D Inc. The facility is located at the Winnipeg James A. Richardson International Airport, in Winnipeg, Manitoba, Canada and the primary use for this facility is to conduct testing on various gas turbine engines. The facility includes a wind tunnel which has 11 fan inlets capable of testing engines that produce up to 150,000 lbs of thrust. The objective of this project is to develop a cover for the fan inlets on the wind tunnel to reduce wind speed through the tunnel when technicians are servicing components, and to mitigate wind-milling of the fan blades.

The final design for the fan inlet cover is made from 18 oz. polyvinyl material and is manufactured by Norwood Tent and Awning, located in Winnipeg, Manitoba. The total weight of each cover is approximately 16.92 lbs. Each individual cover is estimated to cost $388.64 CAD with all of the required parts. The total cost for all 11 fan inlet covers is $4,275.04 CAD. The design of the covers allows for quick and easy installation. The estimated time to install the covers is 117 minutes.

The covers fit over the fan inlet to form a conic shape with the center accommodating the motor and cable that protrudes from the inlet. A foam plank is placed inside a pocket on the inside of the cover to protect from the sharp edges of the motor from piercing the cover. A slit is created to allow for cable to pass through the cover without obstruction. A combination of D-rings and spring snaps are used to close and secure the slit. Velcro flaps are used to go over top of the ratchet and D-rings to protect these components from damage. To secure the cover onto the face of the wind tunnel, a ratchet runs around the circumference of the covers inside sleeves that flare out and are tightened to secure around the lips of the fan inlet.

These covers shield the entire area of the inlets preventing wind and debris from entering the tunnel. This in turn prevents the fans from wind-milling and helps preserve the integrity of the bearings. An additional benefit of the covers is that they make servicing the wind tunnel more comfortable. When technicians are servicing pipes and nozzles inside the wind tunnel in the winter, the primary concern is now limited to the ambient air temperature. The lack of wind significantly improves conditions which aid in reducing time taken to perform work and allows for this work to be done through a wider range of conditions.

In this report, a material analysis, cost breakdown, CAD models, preliminary engineering drawings, vendor list, and bill of materials have been provided.

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Introduction

This report details the design of wind tunnel covers for General Electric (GE) Aviation and West Canitest Research and Development Inc. (WestCaRD). The report will go over the details of the problem statement, and the needs and target specifications identified by the clients. A summary of the concept development for the fan covers highlights key areas of the concept selection that lead to the preliminary design. An explanation of the wind pressure loads on the wind tunnel is made, as this affects the area that each fan inlet cover can shield without compromising the safety factor of the rail locking mechanism. The design is then summarized, along with methods of securing the cover and material chosen, describing all the design aspects and rationale considered.

Background

The General Electric Engine Testing, Research and Development Center (GE TRDC) is located at the James A. Richardson International Airport grounds in Winnipeg, MB. The facility runs tests on engines in various cold weather conditions, using a variety of water and ice mixtures to make up these weather conditions. The wind tunnel is operated by Standard Aero personnel to perform the engine tests. These tests determine how the engine will perform in frigid temperatures. WestCaRD is a Research and Development Manitoba corporation that leverages private and government funds to develop technical capacity with aerospace and aero-engine testing in Manitoba [1]. WestCaRD works with GE TRDC on research and development initiatives. WestCaRD was closely involved with the upgrades of the wind tunnel undertaken at the site to allow the testing of the new line of engines, the GE9X. The new wind tunnel is shown in Figure 1.

Figure 1. GE TRDC wind tunnel [2]

The wind tunnel recently received a 20 million dollar upgrade, with additional fans and supporting infrastructure added to the site [3]. The wind tunnel structure has eleven fans, each powered by a 250 hp electric motor, which can generate winds in excess of 100 km/hr [4]. A close up of a wind tunnel inlet is shown in Figure 2.

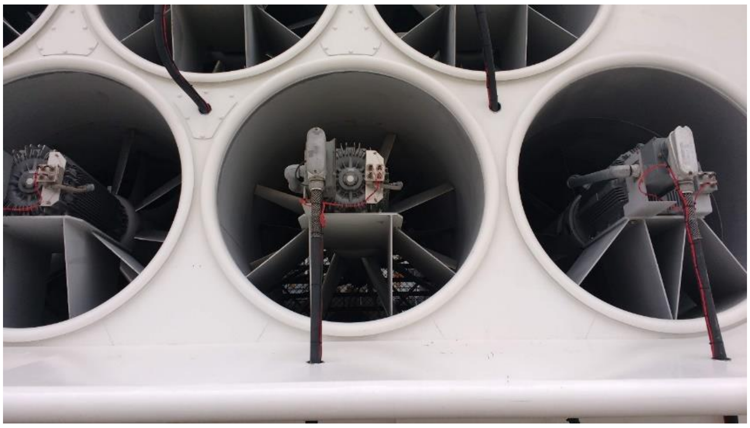

Figure 2. Close up of fan and motor assembly [2]

Each assembly has an electric motor, instrumentation to control the RPM of the motor, a power supply to provide electrical power, and a pedestal to support the motors within each inlet.

The wind tunnel is held in place by two sets of six chocks, with three chocks holding each wheel. Shown in Figure 3 is a set of chocks holding the wind tunnel from rolling backwards.

Figure 3. Chocks clamped on rail to secure wind tunnel wheels [2]

One set of six chocks (three on each side) prevents the wind tunnel from moving forwards, while the other set prevents the chocks from moving backwards. Each chock is able to hold 6,000 lbs of force before becoming ineffective. With a factor of safety of 1.5, each set of six chocks can hold a total of 24,000 lbs of force.

A noise attenuation wall was constructed around the facility to reduce the noise generated by engine testing. The facility can test engines up to 150” in diameter that generate up to 150,000 lbs of thrust, using a single post jet engine test stand. This facility was upgraded to accommodate the newest line of aviation engines, the GE9X, for Boeing’s newest commercial aircraft, the 777X. The wind tunnel was expanded from seven fans to eleven fans in order to accommodate the size of these new engines and ensure proper testing.

Problem Statement

The wind tunnel at GE Aviation TRDC has a wind tunnel with eleven fan inlets that need to be covered while not in use. The fans windmill year-round, as they face the prevailing north westerly winds and cause poor working conditions for the technicians inside the tunnel. The open inlets create cold conditions for the workers during cold months. The inlets also allow for debris, snow, and other contaminants to freely enter the wind tunnel which must then be removed by hand.

The objective of this project is to design a cover for the wind tunnel, to allow a more comfortable and safer environment for the workers, to reduce wind milling of the fan blades which leads to unnecessary wear on the fan bearings, and to prevent debris from entering the tunnel.

Assumptions and Constraints

When designing the cover, several assumptions were made to limit the scope of the project. These assumptions are detailed in TABLE I.

TABLE I
ASSUMPTION DESCRIPTION

#	Assumption
1	The maximum temperature considered is 40 °C and the minimum temperature considered is -40 °C [5]. The rate at which the temperature changes will not be considered.
2	Any additional loads on the wind tunnel itself does not affect the integrity of the wind tunnel, and any analysis required will be conducted by GE Aviation.
3	Differences in fan inlets dimensions are small, so that designing for an inlet will be universal and cover any inlet.
4	The maximum wind loads act perpendicular to the wind tunnel face. Any offset angle of the wind acting on the tunnel is not considered.

In addition to the assumptions, a list of constraints have been identified, which impacts aspects of the final design. The constraints are tabulated in TABLE II.

TABLE II
LIST OF CONSTRAINTS

#	Constraint	Description
1	Project timeline	14 weeks to complete.
2	Design space	Dimensions of inlet area of wind tunnel, up to the end rails that tunnel rests on.
3	Material supplier access and information	Limited to availability of suppliers in contact with team. Ideally from Manitoba, but others may be considered to remain cost effective.
4	Team size	5 engineering students.
5	Installation team size	2 technicians.
6	Cost	Based on most cost-effective method of successfully covering the inlets. Recommendation are supplied in the report.
7	Wind tunnel modification	Prohibited from making modifications to the tunnel.
8	Accuracy of analysis	Dependent on software, method of analysis chosen, and any assumptions established.

Needs and Target Specifications

With the problem statement, assumptions, and constraints identified, a list of needs was created to identify the client's requirements for the covers, as well as quantitative target specifications that tie to their needs. The needs were given ranks of importance, with 3 as a high importance, and 1 as a low importance. The needs are shown in TABLE III.

TABLE III

CLIENT NEEDS

Need ID	Need	Importance
A.	Cover(s) must not add significant loadings to the wind tunnel	3
B.	Can be installed or uninstalled with 2 people	2
C.	Can be installed or uninstalled in less than 2 hours	2
D.	Easy to install	2
E.	Safe to operate	3
F.	Cover is secure when installed	3
G.	Creates a safer working environment	3
H.	Creates a more comfortable working environment inside the wind tunnel	2
I.	Minimizes risk of covers becoming FOD (Foreign Object Debris)	3
J.	Cover(s) are affordable	1
K.	Prevent debris and precipitation from entering the fans	2
L.	Prevent fans from wind-milling	2
M.	Covers are durable, and last a long time	2
N.	Does not obstruct airflow of wind tunnel when fans are operational	3
O.	Can be installed without modifying the existing wind tunnel	2
P.	Can be cleaned with equipment on site	1
Q.	Easy to clean	1
R.	Universal Cover	2

The target specifications and their respective values are indicated in TABLE IV, showing the ideal and marginal values that each criterion must satisfy in order to meet the client's needs. The need ID ties back to which need(s) the target specifications are associated with. The ranks of importance are the same values at those of the client needs.

TABLE IV

TARGET SPECIFICATIONS

Metric Number	Need ID	Metric	Units	Marginal Value	Ideal Value	Importance
1.	A	Total loading on rail locking system	lbf	<32,000	19,100	3
2.	B, E	Weight of cover	lbm	25	<25	3
3.	C	Time to install or uninstall	Minutes	120	<120	2
4.	D	Ergonomics	Subjective	Pass	Pass	2
5.	F, I	Secure when installed	Pass/Fail	Pass	Pass	3
6.	F	Fits regardless of temperature	Pass/Fail	Pass	Pass	2
7.	G, L	Fan speed with covers on	RPM	20	~0	3
8.	H, L	Wind speed inside tunnel	Miles/Hr	6.2	<6.2	3
9.	J	Cost	$[CAD]	10,000	3,500	1
10.	H, K	Blocks debris	Pass/Fail	Pass	Pass	3
11.	M	Fatigue life	Years	10	15	2
12.	M	Wind load that covers can withstand	lbf	850	1,300	2
13.	N	Retractable or removable when fan is in use	Pass/Fail	Pass	Pass	3
14.	N	Portable	Pass/Fail	Pass	Pass	3
15.	O	Wind tunnel unaltered	Pass/Fail	Fail	Pass	2
16.	P, Q	Can be cleaned with a pressure washer or by hand	Pass/Fail	Fail	Pass	1
17.	R	Universal cover for all fans	Number of designs	2	1	2

Summary of Concept Development

In developing the final design of this report, several concepts were considered and analyzed. Through the analysis, one concept was determined to be the most optimal for the needs and requirements stated by the client. This section outlines the concept development stage, highlighting the main decisions and items that were considered leading to the final design.

Method of Covering the Fans

Three main style of fan covers were analyzed during the conceptual design phase. The first concept considered consists of individual fan covers, where each fan cover would block a single inlet on the wind tunnel. The preliminary concept of these individual fan covers is shown in Figure 4.

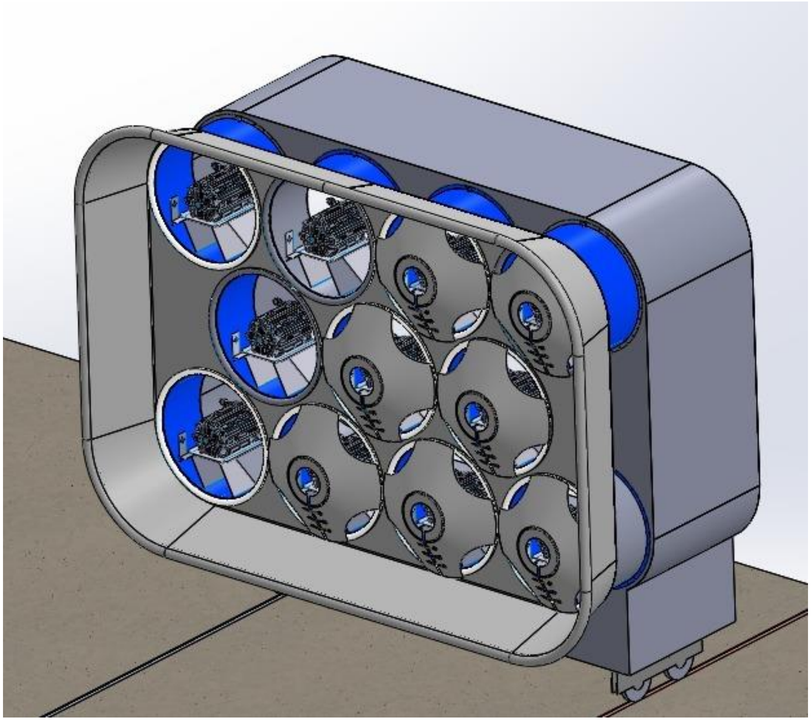

Figure 4. Single fan cover

The second style of cover considered is a separate, free standing, wall structure. This wall would not be attached to the wind tunnel and could be moved out of the way when needed. The wall concept is shown in Figure 5.

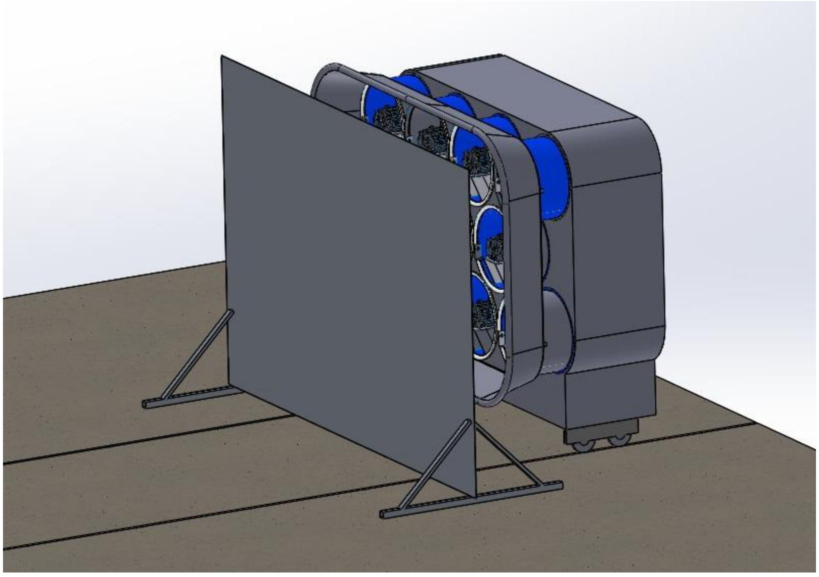

Figure 5. Detached wall structure cover

The last concept analyzed is a permanent retractable multi-fan cover. This cover would be permanently attached to the wind tunnel and would cover all eleven fan inlets at once. This cover concept is similar in style to a garage door, which would be lifted onto the top of the wind tunnel, out of the way of the fan inlets, when not in use. This multi-fan cover is shown in Figure 6.

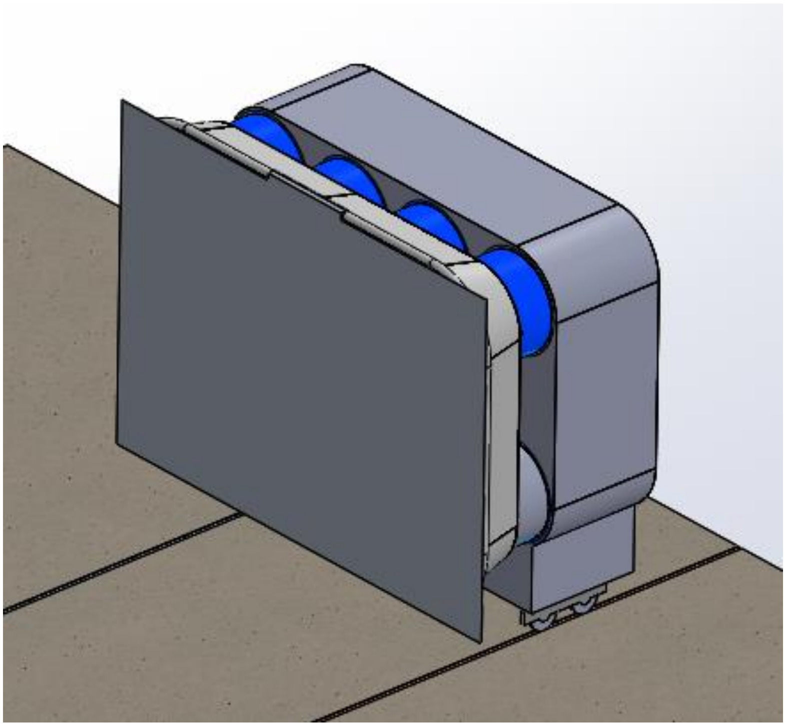

Figure 6. Retractable multi fan cover

A concept screening matrix was created to determine which type of cover would be ideal based on the client's needs and the target specifications. This process is detailed in Appendix A. It was determined that the single fan covers were ideal, and further analysis of the individual fan covers was conducted.

Design of Single Fan Covers

During the concept development process several challenges became evident regarding the possible implementation of the covers. One challenge is the size of the fan covers. The client stated that two workers must be able to install the covers, without any extra help, onto the 8' diameter fan inlets. An 8' rigid cover is heavy and large, making it difficult to work with. Another challenge is the location of the fan motor. An electric motor is attached via a large motor mount to the inside of each fan inlet well. This assembly protrudes from the face of the tunnel, as shown in Figure 7. The cover will either need to move around or extend over the protrusion.

Figure 7. Offset side view of fan motors and mounts

Another challenge regards the fans' power cables. These cables protrude out from the front of the fans' instrumentation box, run down the radius of the fan inlet, then are fed into individual holes through the face of the tunnel, as shown in Figure 8.

Figure 8. Electric cable attached to motor *[2]*

The covers cannot interfere with the power cables and they cannot interfere or damage any of the expensive wind tunnel components. Because the cable extends past the lip of the inlets, an opening on the covers must be designed to allow for the cable to pass through.

The individual cover that best meets and conforms to these challenges, while satisfying the clients' needs, is a flexible material cover. This selected design was compared with five other potential cover designs; the designs were weighted against one another based on appropriate criteria that suited the design conditions and requirements, and the flexible cover was determined as the ideal for the wind tunnel application. The selection process for the individual fan covers is detailed in Appendix B. From this process, the preliminary design of the flexible cover is shown in Figure 9.

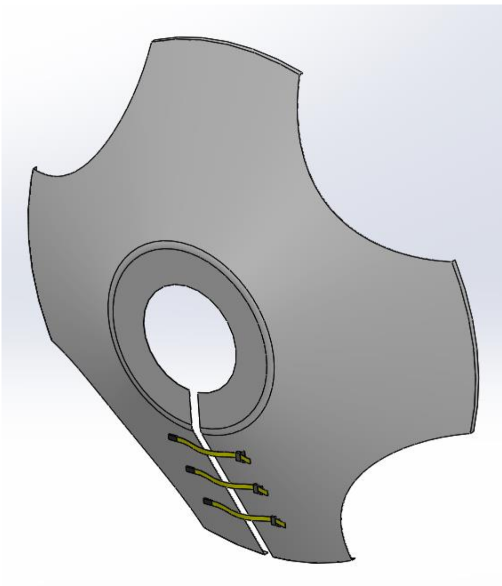

Figure 9. Preliminary material cover design

This cover is composed of polyester vinyl material. This material was selected because polyester vinyl is used for aviation engine covers, which are exposed to similar environments as the covers installed at GE TRDC. The material is also readily available for purchase from various locations online and in Winnipeg. This cover design has a hole in the center to accommodate the motor protruding from the tunnel and cut outs on each corner to reduce the surface area of the cover. Straps are positioned along the bottom of this cover; the purpose of the straps is to close up the slit down the center of the cover, and to tighten the cover around the motor.

The decision to pursue a material cover was ideal since it is flexible, allowing the cover to be form fitted to the shape of the protruding fan motors. Flexible material also allows for easier storage since they can be folded up and take up less space. This polyvinyl cover weighs less than a similar sized cover that would be made from plastic or metal, making installation less strenuous for the technicians.

Based on the allowable wind loads of 119 km/hr [6] on the tunnel face, only 44.5% of each fan inlet may be covered, which is why the concept has cut outs in each corner to reduce surface area to stay within the 1.5 safety factor.

After reviewing with the client, they estimated that 44.5% coverage would not provide sufficient protection from the wind; as a result, they proposed that two additional chocks may be implemented with the current six to increase the allowable wind loading. With the additional two chocks and a factor of safety of 1.5, the maximum allowable wind load is increased from 24,000 lbf to 32,000 lbf. The results of the recalculation and re-evaluation of the allowable cover area is determined in the explanation of the final design following.

Final Design

The final cover design is shown in Figure 10. The cover is designed such that it will shield 100% of the fan inlet area from incoming wind. This new allowable area was established after the recalculation of the wind loading, which is described in a following section. This design is composed of several features that all play an important role in improving the installation, security, and lifespan of the wind tunnel.

Figure 10. Final cover design (uninstalled)

A side view depicting the depth of the cover is shown in Figure 11. The cover is concave and extends out 20” to accommodate the fan motor assembly.

Figure 11. Side view of cover

Figure 12 shows the cover as it would look when installed on a tunnel inlet. The three middle covers are left out to show contrast, however all inlets will be covered during implementation.

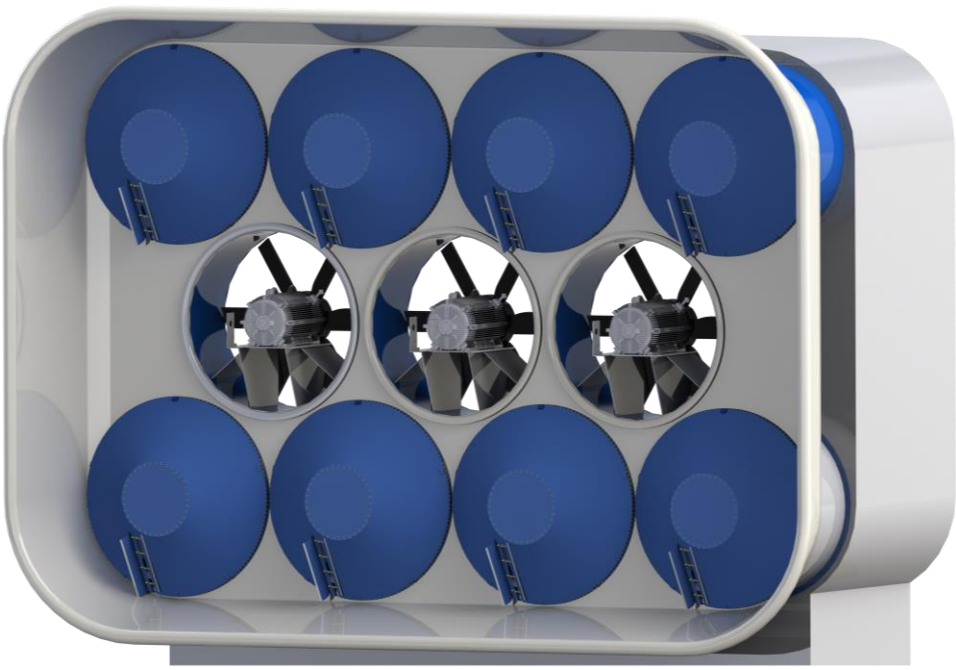

Figure 12. Final design cover installed on wind tunnel

A final design overview is provided below, and detailed explanations of the covers' features are described in the proceeding sections.

Final Design Overview

The features and composition of the final design all contribute towards meeting the required needs and specification presented in this report. The features chosen to meet these specifications are briefly described below.

18 oz. Vinyl Coated Polyester

The covers are made out of a 18 oz. vinyl coated polyester, which can withstand cold temperatures down to -45°C, provides good UV resistance, and is lightweight which allows for easier installation and storage. The material is flexible, conforming to the shape of the objects that is being covered and is waterproof, preventing the permeation of moisture through the cover themselves. Since the covers will be used outside year-round, the durability of the material under these wide range of conditions is beneficial for this application.

Ratchet Securing Mechanism

The ratchet secures the cover to the wind tunnel, where the strap is fed through sleeves encircling the covers circumference. This is shown in Figure 13.

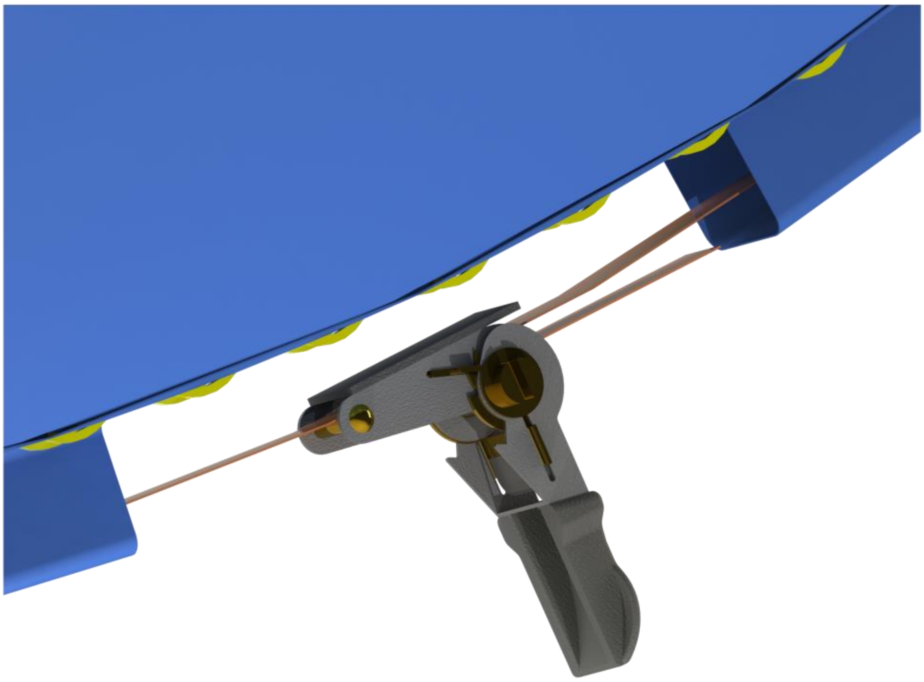

Figure 13. Ratchet and strap for securing cover

The ratchet acts as a draw string which uniformly tightens the cover so that it stays secure on the lip of each fan inlet. The sleeves of the cover are first tucked into the lip around the inlets before tightening the strap, then the ratchet is tightened which secures the cover to the inlet. Six openings are placed along the sleeve of the covers to allow for access of the ratchet.

Magnet Pouches

Six magnets are positioned inside Velcro pouches around the circumference of the cover, as shown in Figure 14. Each magnet has a pull force of 19.4 lbf which will help tack the cover to the wind tunnel while the cover is being installed. The magnets will help secure the cover to the wind tunnel once installed.

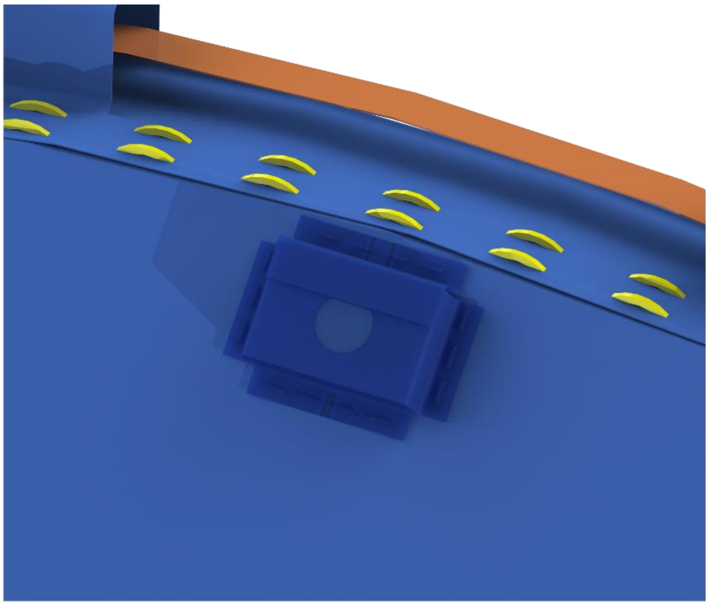

Figure 14. Magnet pouch

D-ring and Spring Snap Clips

D-rings and snap clips are utilized to secure the two halves of the slit together. There are four pairs spaced 10” apart along each side of the slit, as shown in Figure 15.

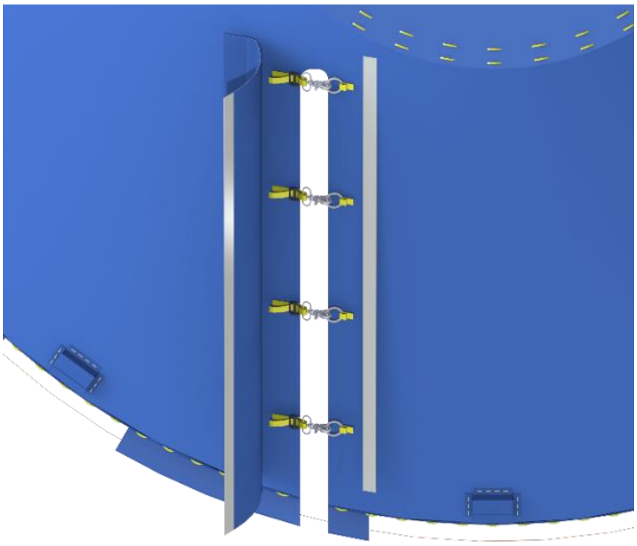

Figure 15. D-Ring and spring snap clip joining

Velcro Flap for Weather Protection

The Velcro flap is used to protect the D-ring and snap clips from environmental elements while also ensuring that the cover is fully sealed and blocks all wind and potential debris. The flap is sewn on the left side of the snap clips, shown in Figure 15, and the flap joins to the grey Velcro strip on the right side of the snap clips.

Foam Insert to Protect Cover

The foam insert on the back of the wind tunnel cover is used to protect the cover from the sharp metal edges on the power supply cable, and provide some cushioning to the cover when being tightened on the face of the tunnel. The pocket is shown in Figure 16.

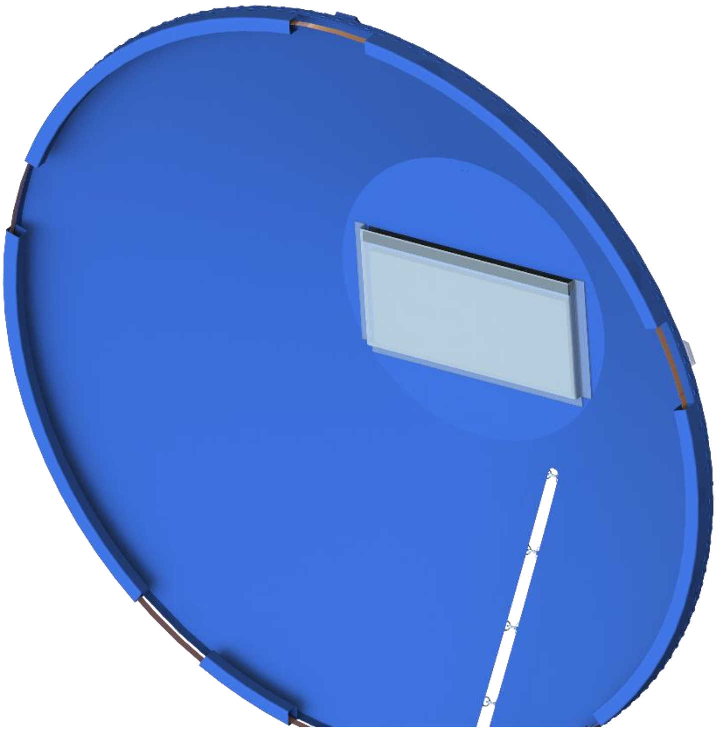

Figure 16. Foam insert located at the rear of cover

The pocket is closed using Velcro along the top of the pocket. This allows a simple means of sealing the pocket and will allow easy access to the foam if replacement is warranted.

Max Allowable Load on Wind tunnel

For the original loading constraints on the wind tunnel, which allowed for only six rail locking chocks, the maximum allowable force that could be applied to the tunnel was 24,000 lbf (or 36,000 lbf with no FOS). Under this constraint, as stated previously, the maximum percentile that the covers would be able to shield the inlets is 44.5%. With permission from the client at GE TRDC, two more chocks are available for use. With eight chocks the new maximum allowable force that can be applied to the tunnel face is 32,000 lbf (or 48,000 lbf with no FOS).

The optimal cover area was determined by taking several iterations of the percentage covered and comparing the resulting wind load with the allowable load of 32,000 lbf. This process is described in Appendix C. With an internal goal of having the inlets 70% covered, the iterations were computed from 70% to 100% covered. The results of these calculations are tabulated in TABLE V.

TABLE V

WIND LOAD FOR DIFFERENT COVER PERCENTAGES

Percent covered	Load on rails [lbf]	FOS 6 chocks	FOS 8 chocks
44.5	24,000.00	1.50	2.00
70.0	26,817.07	1.34	1.79
80.0	27,921.90	1.29	1.72
90.0	29,026.72	1.24	1.65
95.0	29,579.13	1.22	1.62
100.0	30,131.54	1.19	1.59

Each iteration of the “Percent covered” shows the corresponding loading that the chocks would experience. If the loading on the tunnel is smaller than the max allowable load, then a larger difference can be considered as an increase towards the factor of safety. The two right-most columns of the table show the resultant factor of safeties due to the loading at different “Percent covered”. The 6-chock configuration is listed as a reference for improvement when compared to the 8-chock configuration. When comparing the two configurations with the original 44.5% covered, the 8-chock configuration yields a FOS of 2. Increasing the “% covered” to the maximum possible option of 100%, the wind load remains lower than the maximum allowable load of 32,000 lbf for the 8-chock configuration, with the resultant factor of safety is 1.59.

With the addition of two more chocks, not only did the allowable percentage covered increase to 100%, the factor of safety also increased. For this reason, the final cover is designed to fully shield the wind tunnel inlets.

Cover Material

The material used for the final fan cover design is 18 oz. polyester vinyl. In making this decision, an analysis was performed where several different materials were compared against one another using relevant criteria. Through the analysis, the polyester vinyl was determined to be the best material for the application of the covers. This analysis can be viewed in Appendix D.

The 18 oz. polyester vinyl material provides a high strength to weight ratio. Compared to other types of polyester vinyl, the 18 oz. material offers sufficient strength for the environmental conditions while maintaining a low weight. This material allows several features to be added to the covers which are required for securing the cover to the wind tunnel.

Given that the covers will spend a significant amount of time outside, polyester vinyl’s superior water and UV resistance are key considerations when selecting the material. The covers will be left on the wind tunnel for prolonged periods of time during the summer due to the limited testing being conducted. The high UV resistance helps to preserve the lifetime of the cover and protect it from the high exposure to sun. In the case of precipitation, the covers are impermeable to water.

To ensure the covers will not tear during operation, an analytical stress analysis was conducted to determine the maximum stress that the covers may experience during operation. This analysis is detailed in Appendix E. This maximum stress the covers will experience due to wind load was determined to be 11.37 lbf/ft^2. The 18 oz. polyester vinyl has a tensile strength of 440 lbf/in^2, therefore there is no risk of the material ripping during operation.

Securing Method

As mentioned in the final design overview, a ratchet strap is utilized on the final design as the method of securing the covers to the fan inlets. In making this decision, an analysis was performed analyzing the benefits and drawbacks of several different securing designs. At the end of this analysis, the ratchet strap was determined to be the concepts with the most merit, based on the desired criteria. This analysis can be viewed in Appendix F. Along with the ratchet, a series of magnets are also located around the circumference of the inlet. These magnets help during the installation process, as well as help provide extra holding strength and security.

The ratchet strap allows the technicians to connect and tighten the covers to the fan inlets quickly and efficiently. To do this, the strap will be fed through sleeves that run along the rear circumference of the cover, as shown in Figure 19, such that the two ends of the ratchet strap meet at the bottom of the cover. This process will be performed on the ground prior to installation. Once the strap is installed, the cover can then be installed on the inlets. A detailed list of instructions describing the method of installing the cover is presented in Appendix I.

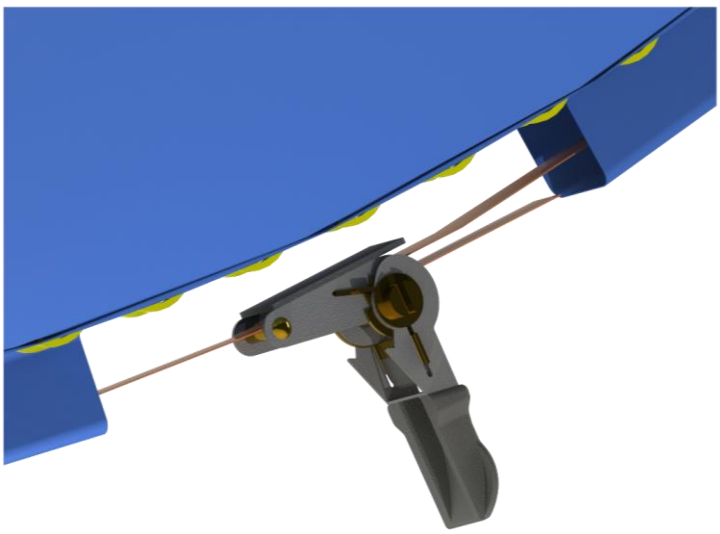

Figure 17. Ratchet and strap for securing cover

Once installed, the ratchet strap is tightened, securing the cover to the inlet lip. The strap provides a uniform force around the entire circumference of the fan inlet, reducing the possibility of stress concentration on the cover and reducing the possibility of the cover buffeting in the wind. An image of the strap and cover sleeve cross section is shown in Figure 18.

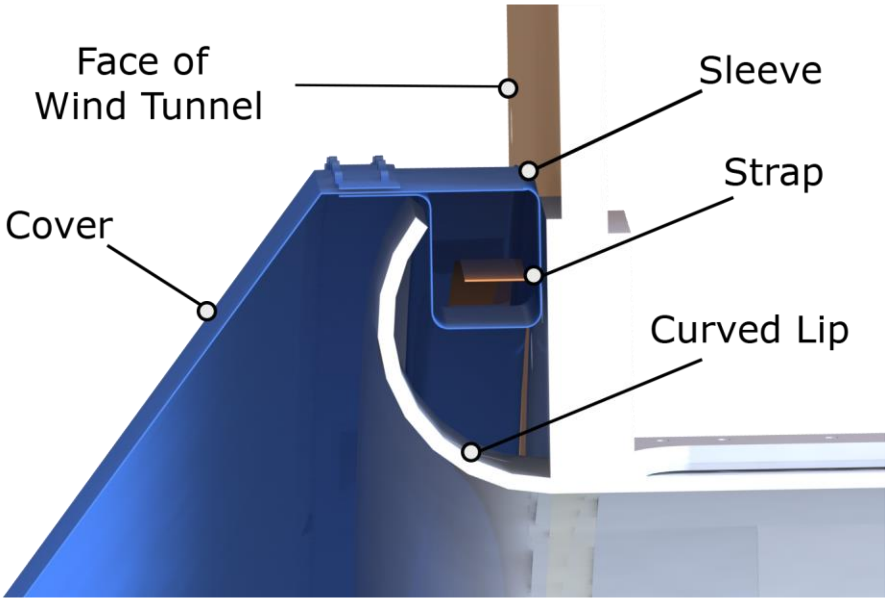

Figure 18. Cover installed on wind tunnel cross section

The sleeves surrounding the cover are not continuous and have openings at six different locations, as shown in Figure 19. These openings serve two purposes; to make weaving the strap through the sleeves easier, and to create openings for the ratchet to be accessed.

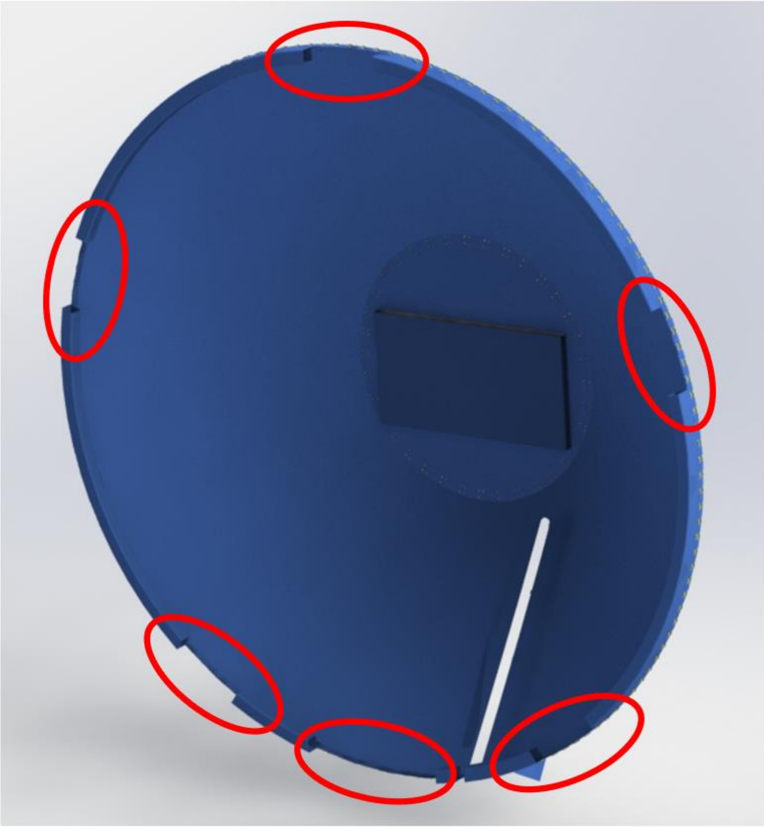

Figure 19. Cover sleeves

Depending on the location of the inlet, the ratchet will need to be positioned at specific sleeve openings. It must be noted that the strap cannot run across the cover slit during installation or uninstallation due to interference with the cable; therefore, to reduce unnecessary re-weaving the strap through the sleeve after installation, the ratchet must be located at one of the three bottom sleeve openings. Regarding the ratchet location, shown in Figure 20 is the bottom right fan inlet. As seen around the edge of the inlet, there is not enough clearance for the ratchet to be effectively tightened if positioned at the bottom, or bottom right opening of the cover. The only position that the strap could effectively be tightened on this inlet is at the bottom left corner. A similar situation exists for the bottom left inlet; for the bottom left inlet, the only location the ratchet can be tightened is at the bottom right sleeve opening. For ease of installation, an explanation of the recommended ratchet locations is also presented in the installation manual in Appendix I.

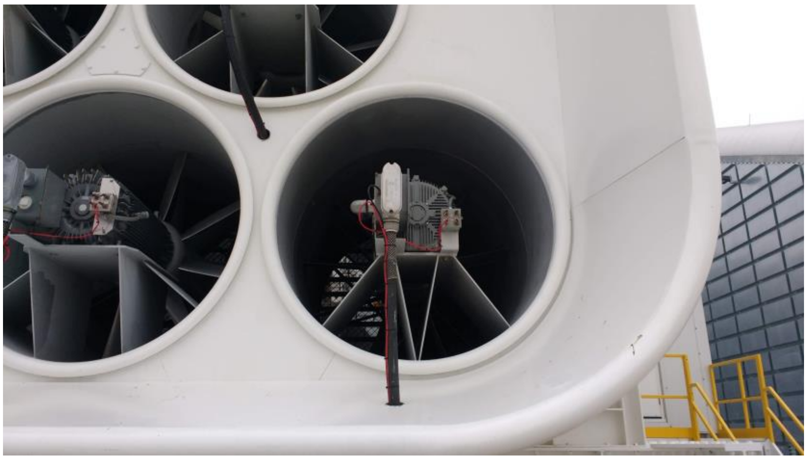

Figure 20. Clearance of corner inlets

The ratchet strap required for the inlet covers application needs to be strong, resistant to the anticipated weather conditions, and large enough to fit around the 25-foot circumference of the inlets. Sourced in Appendix G, a strap that meets these needs is an 'Endless tie down strap' from Uline [7] shown in Figure 21.

Figure 21. Endless tie down strap [7]

Unlike most ratchet straps, which feature the ratchet and the strap as separate components, the endless ratchet strap is one piece, and can be looped around the cover and fed back through the ratchet without the need of secondary connections. The strap sourced is 27' long, 2" wide, and has a working load limit of 1,600 lbf and an ultimate breaking strength of 5,000 lbf [7]. The maximum wind load any cover will experience is 841.29 lbf, as calculated in Appendix E which is significantly lower than the loading limit; therefore, these straps are well suited for the application.

In addition to the ratchet strap, six magnets are positioned around the circumference of the cover to help secure the cover and to make installation easier. As mentioned, to allow for accessibility of the ratchet, there are openings along the outer sleeve of the cover. The drawback of these openings is the ratchet is not able to secure the cover at those key locations. The unsecured locations will flutter in the wind and become potential locations for failure of the cover. In recognition of this potential failure, the six magnets will be positioned at the locations of the sleeve openings, as shown in Figure 22.

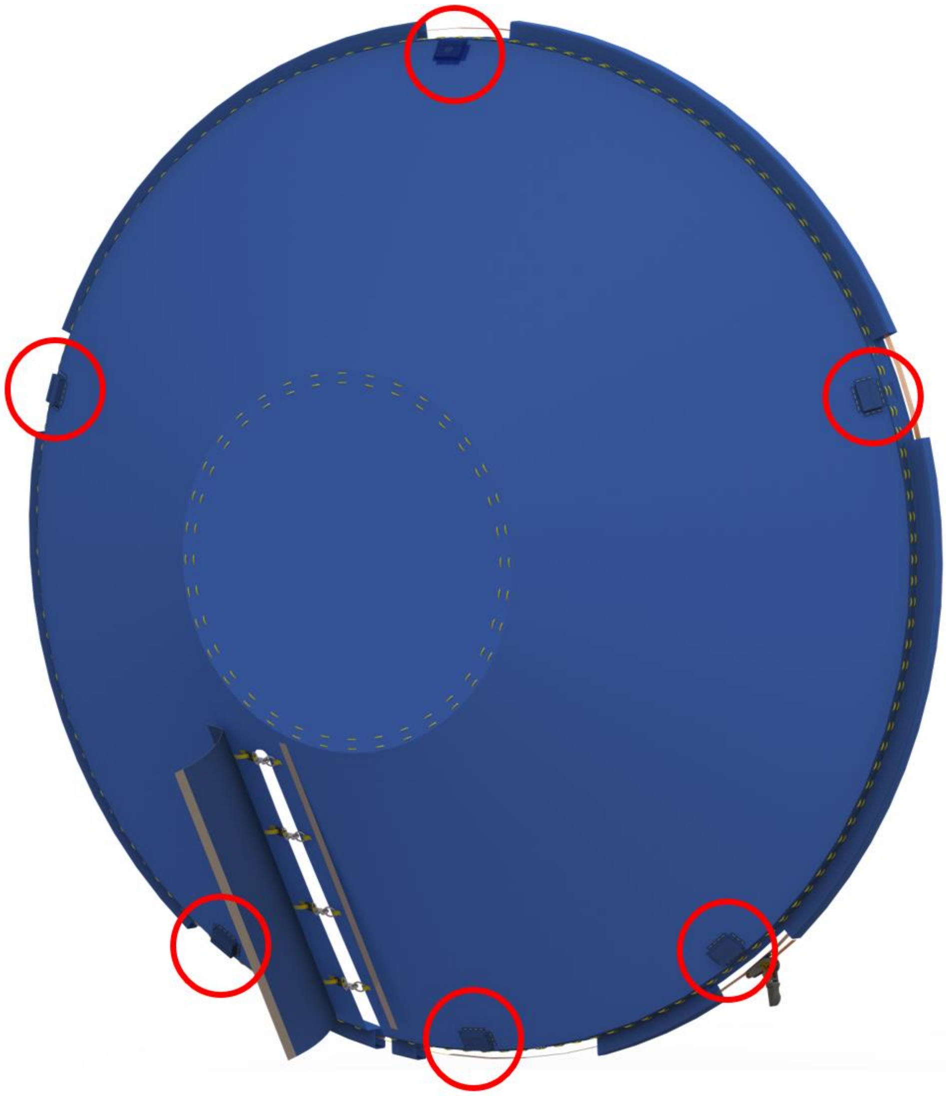

Figure 22. Locations of magnets

Each ¼ inch magnet has a pull force of 19.4 lbf and are placed in Velcro pouches for accessibility in case a replacement is required. The magnets will contact the lip of the wind tunnel and will prevent wind from getting behind the covers. Another benefit of the magnets is they make installation of the covers faster and easier. The technicians will be able to hang the cover from the magnets before securing them, meaning they do not need to fight with the cover to keep them in place while trying to tighten the ratchet strap.

Rejoining Method

The cover slit is required due to the protruding cable connected to the fan motor which extends down past the inlet opening. The slit allows the cover to wrap around the cable, and completely cover the inlets, however the slit needs to be rejoined otherwise the cover would not be secure, nor would it block air flow as intended.

The method decided for rejoining the two halves of the slit is a combination of snap clips and D-rings placed on opposite sides of the slit. In making this decision an analysis was performed, similar to the analysis for the securing method, in which the benefits and drawbacks of several different designs were analyzed. At the end of this analysis, the spring snap and D-ring was determined to be the most optimal and is used in the final design. This analysis can be viewed in Appendix F addition to the snap clips, a Velcro flap is sewn along the slit. This flap will help secure the cover and protect the snap clips from ice and debris.

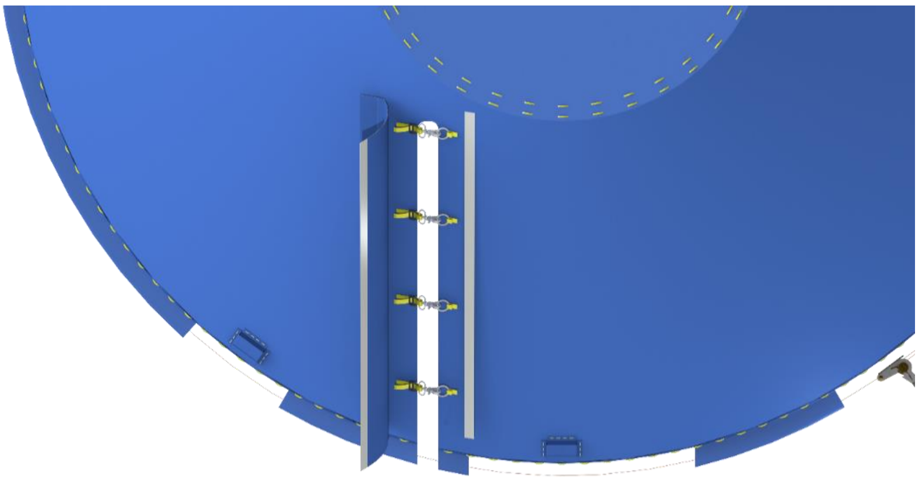

Figure 23. Cover slit

On the left side of the cover slit is a series of four snap clips spaced 10” vertically apart, as seen in Figure 23. Along the right side of the slit, in line with the snaps, is a series of D-Rings. When joining the two sides of the cover slit, the spring snaps lock onto their corresponding D-rings. The d-ring provides a secure connection and is easy to attach, which is ideal when working with bulky winter gloves. Shown in Figure 24, the snap clips connect to the cover on short straps threaded with strap locks. The strap lock allows the distance of the strap to be adjusted; if the cover is not positioned correctly, or is loose, the locks can be adjusted to allow for a more secure fit. A detailed list of instructions describing the method of joining the cover slit is presented in Appendix I.

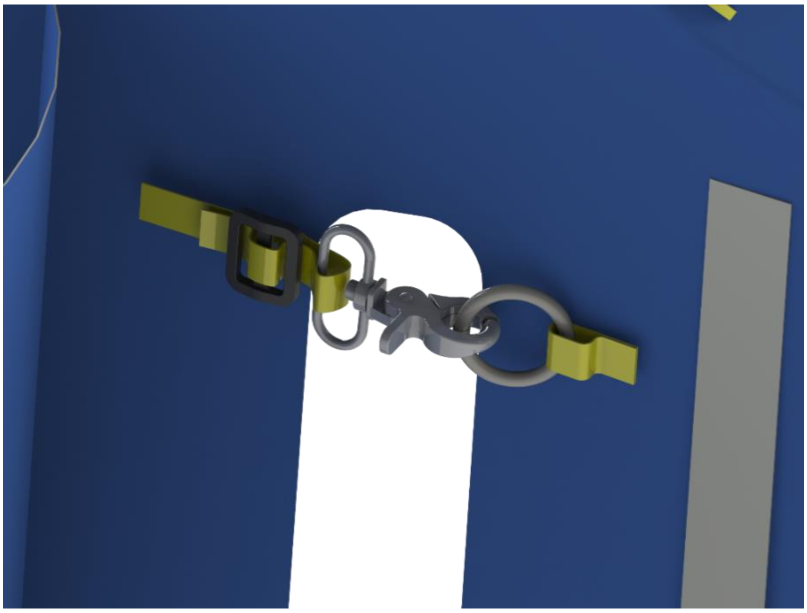

Figure 24. D-ring and spring snap locking mechanism

To ensure that the snaps do not ice up during the winter, a secondary joining method is used in conjunction with the primary method. The selected method to fulfill this requirement is a Velcro flap, as it is simple to attach and detach and will not interfere with the primary joining method. The Velcro flap is sewn on the outer side of the spring snap clips. The flap will then reach over the slit, covering the spring snap clips and D-rings, and attach at the outer side of the D-rings.

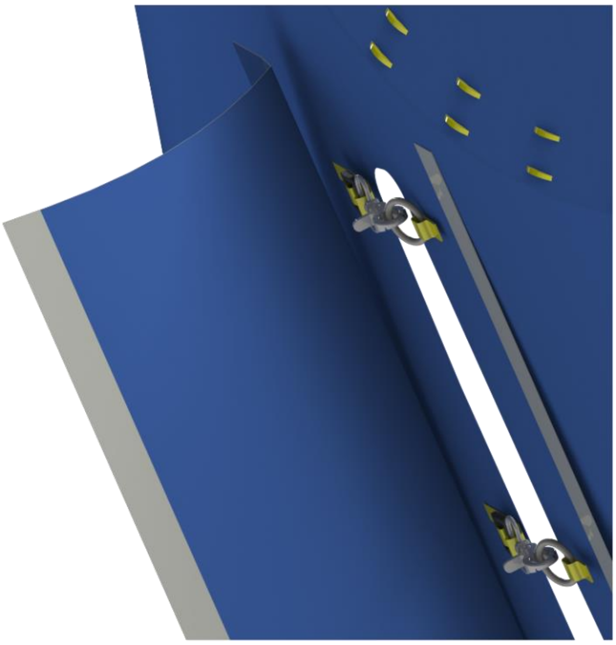

Figure 25. Velcro strip

This strip of Velcro provides a quick method of covering the slit on the cover and keeps the wind from penetrating through to the other side.

Material Protection

A foam insert is installed inside a pocket located on the rear face of each fan cover, as shown in Figure 26. This insert will protect the cover from the sharp edges around the fan motor and allows the covers to have a tight fit on the inlet without the risk of tearing. The foam insert is positioned in front of the motor cable, as it is the furthest protruding section of the motor assembly. The dimensions of the foam insert is 12" by 30" and extends beyond the motor cable, allowing it to wrap around and provide more protection.

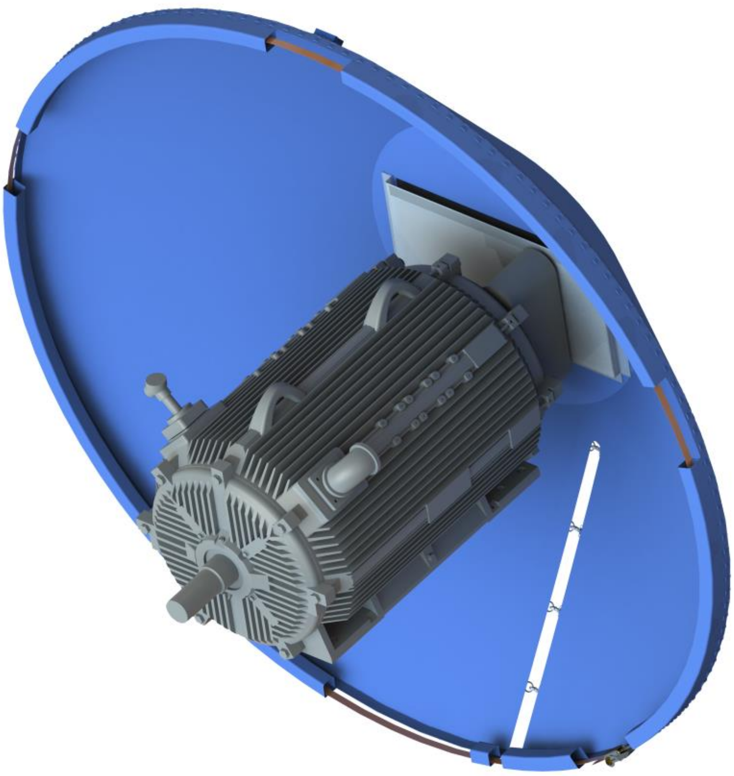

Figure 26. Foam insert pressed against motor power cable

This pocket uses Velcro attached to the inside of the pocket which simply presses up against the rear of the cover to secure closed, as shown in Figure 27.

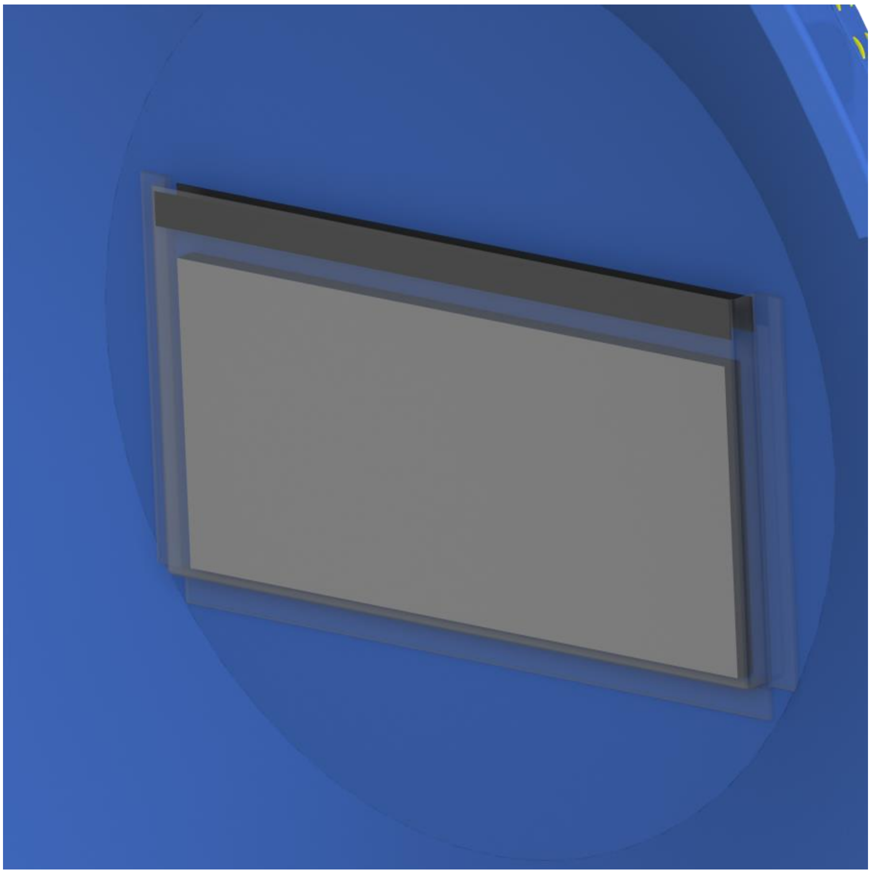

Figure 27. Foam insert

This pocket allows for the protective foam block to be easily replaced if necessary. In its position, the foam only experiences low tensile stresses and tear; therefore the foam will have a long life.

Fulfillment of Clients Needs and Target Specifications

Several needs were developed at the beginning of the design process. These needs were required to fulfill the design and ensure that the covers would be effective. These needs are revisited in TABLE VI, which states whether they met the required ideal or marginal target specifications in the right hand column. The following legend descriptions illustrates the target specifications and the level these metrics achieved.

Ideal = Ideal target spec achieved

Marginal = Marginal target spec achieved

Fail = Target spec not achieved/ No quantifiable measure

TABLE VI

FULFILLMENT OF TARGET SPECIFICATIONS

Metric Number	Need ID	Metric	Units	Marginal Value	Ideal Value	Design Value	Need Met?
1.	A	Total loading on rail locking system	lbf	<32,000	19,100	30,131.54	**Marginal**
2.	B, E	Weight of cover	lbm	25	<25	16.44	**Ideal**
3.	C	Time to install or uninstall	Minutes	120	<120	117	**Marginal**
4.	D	Ergonomics	Subjective	Pass	Pass	Pass	**Ideal**
5.	F, I	Secure when installed	Pass/Fail	Pass	Pass	Pass	**Ideal**
6.	F	Fits regardless of temperature	Pass/Fail	Pass	Pass	Pass	**Ideal**
7.	G, L	Fan speed with covers on	RPM	20	0	~0	**Ideal**
8.	H, L	Wind speed inside tunnel	Miles/Hr	6.2	<6.2	~0	**Ideal**
9.	J	Cost	$[CAD]	10,000	3,500	4,275.04	**Marginal**
10.	H, K	Blocks debris	Pass/Fail	Pass	Pass	Pass	**Ideal**
11.	M	Fatigue life	Years	10	15	N/A	**Fail**
12.	M	Wind load the covers can withstand	lbf	850	1,300	1,600	**Ideal**
13.	N	Retractable or removable when fan is in use	Pass/Fail	Pass	Pass	Pass	**Ideal**
14.	N	Portable	Pass/Fail	Pass	Pass	Pass	**Ideal**
15.	O	Wind tunnel unaltered	Pass/Fail	Fail	Pass	Pass	**Ideal**
16.	P, Q	Can be cleaned with a pressure washer	Pass/Fail	Fail	Pass	Pass	**Ideal**
17.	R	Universal cover for all fans	Number of designs	2	1	1	**Ideal**

The final cover design met most of the needs with an ideal outcome. A discussion of the marginally met and failed needs is provided in the following section.

Metrics Marginally Met

Metric 1 - Total loading on rail locking system

The current load on the wind tunnel, at the maximum possible wind speed with no covers attached, is 19083.31 lbf. This is the ideal case as it implies that no additional loads are applied to the tunnel. Many of the other needs required full coverage of the inlets in order to be ideal, therefore the final cover design utilized a fully covered inlet. This results in a total loading on the wind tunnel of 30,131.54 lbf. Using the eight rail-chock configuration, the max allowable load that can be applied on the wind tunnel is 32,000 lbf. The load on the wind tunnel when fully covered is lower than this maximum value, therefore the metric is marginally met

Metric 3 – Time to install or uninstall

The time to install all covers onto the wind tunnel is estimated to be 117 minutes. Though this value is lower than the target value of 120 minutes, it was marked marginal because any errors or deviations in the procedure may cause the installation time to be longer. There are several factors that are dependent on the operators such as the setup of equipment and is dependent on how many covers can be lifted into the basket of the Skyjack to install. The time provided is an estimate, and once the procedure is completed multiple times, it will become more routine and installation time will decrease. The details for the installation and breakdown of steps is detailed in Appendix I.

Metric 9 – Cost

No price range was given at the start of the project, with the only direction being that the cover must not be too expensive. This is a subjective metric, so the costs were chosen through researching different materials and components. After evaluating a wide range of components, the ideal value was selected to be $3,000 total, with a marginal value of $10,000. The total cost of the design, along with its accessories, is $4,275.04 CAD from Norwood Tent and Awning. The decision to produce the covers are up to the client, as other vendors may be favourable. The option from Norwood Tent and Awning suits the needs of the client and is manufactured at a reasonable cost.

Metrics Not Met

Metric 11 – Fatigue life

The only metric that was not successfully met is the fatigue life of the covers. Fatigue life testing was not found for the 18 oz. polyvinyl cover chosen, with most tensile testing and endurance testing done on PVC plastics, and not on the vinyl coated polyester material.

Bill of Materials and Preliminary Engineering Drawings

TABLE VII presents the materials required for each cover, their associated cost, and the estimated total cost of all covers and installation equipment required.

TABLE VII

BILL OF MATERIALS

Item	Vendor	Cost [$CAD]	Weight [lbs]	Quantity
18 oz. Vinyl Cover	Norwood Tent and Awning	$290.00	11.05	1x11
1" D-Ring 3250	Norwood Tent and Awning	$0.69 [8]	0.1875	4x11
1" Spring Snap 5016	Norwood Tent and Awning	$2.74 [9]	0.15	4x11
1" Strap Lock	Amazon	$3.15 [10]	0.04	4x11
2" Velcro	Amazon	$9.90 [11]	0.25	1x11
1" Diameter Magnet	Acklands Grainger	$4.37 [12]	0.08	6x11
Ratchet and strap	ULAND	$33.00 [7]	3.29	1x11
Bar Clamps*	Acklands Grainger	$30.48 [13]	1.55	3
Polyfoam (12" x 30")	Foam Factory	$3.20 [14]	0.335	1x11
Weight per Cover [lbs]	16.92			
Cost per Cover	$388.64			
Total Cost	$4,275.04			

*Note: Only 3 bar clamps are required for ***all*** eleven covers and will be reused during installation.

The covers are recommended to be manufactured from Norwood Tent and Awning, and each cover costs an estimated $388.64. The total price for all eleven fan covers and installation equipment required for installation and uninstallation is $4275.04. The associated vendors that the items may be purchased from and indicated in the table.

The preliminary engineering drawings are found in Appendix H. This appendix includes the drawing of the vinyl coated polyester, as well as an assembled drawing of the cover and all of the accessories.

Conclusion

This project was initiated to allow for more comfortable and safer working environment inside the wind tunnel at GE TRDC. This was accomplished by creating individual covers for the eleven fan inlets. The covers designed allow each fan inlet to be covered fully in order to protect the technicians from cold working environments. The covers block the wind from passing through the inlets which prevent wind-milling of the fans, thus reducing unnecessary wear on the fan bearings, and also protect the motors from rain, snow, and debris. The final design is shown again in Figure 28.

Figure 28. Final wind tunnel cover

The cover is made from 18 oz. vinyl coated polyester, which is ideal for cold winter conditions. The cover has a slit to accommodate the power cable from the motor. The slit is attached together using four sets of adjustable D-rings and spring snaps, with a flap and Velcro strip for easy installation. The cover itself weighs 11.05 lbs, and 16.44 lbs in total with all other accessories. The cover features a foam insert behind the center circle, which protects the cover from the sharp edges on the power cable and instrumentation box on the fan motors. A ratchet and strap is enclosed in the outer sleeves of the cover, which secures the cover to the wind tunnel. Six magnets are placed in pouches along the outside of the cover, which aid in placing the cover in the proper position before securing with the ratchet.

The estimated cost of each cover is $388.64, with all eleven fan covers and their accessories coming to $4,275.04 from Norwood Tent and Awning, located in Winnipeg. This is one of the most cost-effective methods of covering up the wind tunnel inlets comparing to the other four vendors contacted to design the covers and are able to accommodate all the specific features of the cover design.

Final Recommendations

The following recommendations should be considered prior to implementation of the design.

Dimension validation

The dimensions for the power cable are not provided with the CAD models of the wind tunnel, motor mounts and motors. Additionally, the four corner fan CAD models are not available, which may have slight dimensional differences from the other fans as they were installed at a different date. This would have to be physically verified, in order to ensure proper dimensions for the cover, in order to successfully secure the covers to the wind tunnel.

Testing the cover

Before manufacturing all eleven covers, a prototype should be manufactured and tested in order confirm the viability of the proposed design. This will allow the technicians to use the cover, determine if the proposed installation guide is practicable, and see if there are any other design aspects that need to be changed, that may have not considered.

Using only 6 chocks

Using the current design, additional chocks need to be added to the wind tunnel in order to fully cover the inlets. If this is a concern to others involved with the testing conducted at GE TRDC, then only using five covers and placing them in specific locations to block the wind may be an option. This would block the wind in the locations that the technicians are working at. This is not the most ideal solution, but is a compromise if any other issues are presented with the addition of more chocks.

Labeling each cover with stitching

The covers may have stitching placed at certain locations on the covers, in order to help orientate the technicians with which side must face up, and which cover goes onto which inlet. Only one cover would be different due to the constraint of ratcheting locations on the tunnel, and this cover may be clearly identified with stitching to separate the cover from the others.

Box for transport and storage

Boxes may be purchased for use to store the covers, as well as aid in transporting them to the wind tunnel form storage. This would keep the covers protected, lower the possibility of the covers from falling out of the lift when being hoisted onto the tunnel, and would allow any potential tools that the technicians carry to be kept in this box. The size of the folded covers would be determined first to establish the size of the box, and how many covers will fit in each.

Analyse magnet strength

The six magnets that are used to “tack” the cover to the tunnel lip may be swapped if the 20lb pull force magnets are too cumbersome to use, either during installation/uninstallation or during storage. These are put in place to further help the technicians place and secure the covers as they are large but may be swapped out for a lower or higher pull depending what makes it easier for the technicians. The covers also are designed so that the magnets can be replaced, so if it is determined that they are completely undesired, they may be removed as well.

First time installation, and installation guide

An installation guide is supplied with this report, in Appendix I, to ensure that the covers are installed safely and properly. Since no practical testing of the installation process was conducted, modifications may be needed to improve the installation process, and may be suggested by the technicians installing them.

When receiving the covers for the first time, the ratchet strap will have to be fed through into the sleeves. This will require fish tape, or another tool to feed the strap through the sleeves. Once installed, the strap will stay a part of the cover, and will only need to be removed if replacement is warranted.

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Appendix A – Determining Single Fan Cover or Multi Fan Cover Design

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List of Tables

This appendix elaborates on the summary of concept development section. The metrics that were used to compare each type of design are discussed, followed by a decision matrix that determined that the single fan cover design was the optimal solution for the design. An explanation of the metrics is established first.

Metrics are selected in order to compare the individual fan cover, detached wall structure, and the attached retractable multi-fan cover, each type of design does not compare fairly in certain areas to one another. For example, weight is an important metric for the individual fan covers, as they will be installed by hand. However, weight is not a concern for the multi-fan cover and wall since they can be moved using equipment such as forklifts or other machinery. For this reason a list of criteria was developed that could be associated to each type of design, thus eliminating bias towards one design. The criteria used to compare the cover types is seen in TABLE I.

TABLE I

CRITERIA COMPARING SINGLE VS MULTI FAN INLET COVERS

#	Criteria
1	Loading on the rails due to wind pressure
2	Time to install the covers
3	Ease of installation
4	Cost of the covers
5	Estimated fatigue life
6	Cover portability
7	Requirement for the wind tunnel not to be altered
8	Wind speed through the tunnel
9	Cover simplicity
10	Footprint or storage space that covers take up while not in use
11	Requirement for additional resources such as electricity or machinery

TABLE II uses these eleven criteria's to compare the three cover types. The covers are given a "+", "-", or "0" to state whether it is better, worse, or the same when the criteria of each design is compared to the reference. The individual fan covers are used as a reference. All of the pluses are added up, with all of the minuses subtracted from the total number of pluses. The type of design with the highest score yields the ideal design and is selected. The results are shown in TABLE II.

TABLE II

DECISION MATRIX FOR SINGLE VS. MULTI-FAN COVERS

Criteria	Individual Fan Inlet Cover	Multi-Fan Inlet Cover	Wall Structure
Loading on rail	0	0	+
Time to install	0	+	+
Ease of Installation	0	+	+
Cost	0	-	-
Fatigue Life	0	+	+
Portable	0	-	-
Wind Tunnel Altered	0	-	0
Easy to Clean	0	-	-
Wind speed through tunnel	0	0	0
Simplicity	0	-	-
Footprint	0	0	-
Additional Resources (electricity or truck/forklift)	0	-	-
Number of "+"	0	3	4
Number of "-"	0	6	6
Total Score	0	-3	-2
Ranking	1	3	2

Though the two types of large covers are advantageous for some of the criteria, the individual fan covers are determined to be more advantageous and yielded the highest score. The justification for the ranking of each criteria is as follows:

Loading on the rail

The detached wall structure is considered to be the best, because it does not impose any additional load onto the wind tunnel. The structure is completely separate from the wind tunnel, and will not affect the rail locking mechanism in any way, which is why it is favourable over the other two designs.

Time to install

The wall and multi-fan cover are quicker to install than the individual covers. The smaller covers have to be installed individually onto the inlets, and would take more time for each installation and uninstallation. The two large covers would take a long time to initially set up, as the multi-cover needs to be permanently installed on the cover and the wall would have to be built, but implementation would be fast thereafter.

Ease of installation

The wall and multi-fan covers are easier to install once they are built and put into place on site. They simply have to be moved into place, and do not require repetitive motions like the individual fan covers do. This makes it easier for the workers to install these multi fan cover, as they have access to equipment to help them move the large covers, as opposed to moving the covers by hand and being hoisted by a cherry picker to the tunnel inlets to be installed.

Cost

The multiple individual covers are a much better alternative with respect to cost, as compared to the other two designs. The small covers require less material overall to cover the fan inlets, and do not require additional resources such as power, supporting structures and modification to the wind tunnel in order to function properly. The detached single cover would require additional locking mechanisms and analysis in order to determine how it would be affected by wind, with other components analyzed in order to determine if it would be a feasible design. The two larger covers become much more complex due to their relative size, and would therefore be much more expensive to implement.

Fatigue life

The two larger covers have a better fatigue life than the individual fan covers. They would be made of metal due to their relative size, which would increase their overall strength and resilience. The individual covers have to be taken on and off frequently, which causes wear and tear on certain parts of the cover. This leads to an overall shorter life span of the individual covers.

Portability

The individual covers are more portable than the two larger covers. The large covers have a larger footprint, and are more difficult to move around the site. The individual covers are to be taken off manually and stored in the workshop, ideally not requiring any heavy machinery to move them. If further modification to the tunnel are made, or repairs were required to be undertaken on the tunnel, the small covers are easier to remove and therefore a much better candidate with respect to this criteria

Wind tunnel altered

The only design that would modify the tunnel is the multi-fan cover attached to the wind tunnel, which is why it received a negative score compared to the other two designs. Mechanisms to move the cover in front of the tunnel, and supports would have to be installed, which would require significant modification to the tunnel. Since the clients strongly advised against a solution that has modification to the wind tunnel, it is considered a substantial negative impact on the score of that particular design.

Easy to clean

The multi-fan and wall covers are more difficult to clean of snow, ice and other debris. This is simply due to their relative size, as the smaller covers have a smaller footprint to cover and require less time to clean.

Simplicity

The manufacturing, reliability, and cost decrease with a simple design. With the larger cover types, they require much more complex designs, making them more expensive and harder to analyze than if they are a smaller. The wall and multi-fan covers require additional resources, such as equipment to move them in place, and additional components to keep them secure. The single fan covers would be less complex to analyze due to their smaller scale, and would be installed with already available equipment on site. Therefore, the two larger covers are negatively impacted and perform worse in this category than the single covers.

Footprint

This is only negatively impacted by the large wall structure. This structure has to be stored somewhere on the site, and would take up large amounts of space, which may not be ideal depending on what other operations take place at the site. There is limited space to manoeuvre due to the sound attenuation wall and surrounding buildings, so moving a large structure is another challenge that needs to be addressed when designing a large cover.

Storage Space

This is better for the multi-fan cover, and worse for the wall structure as stated in the previous paragraph. The attached multi-fan cover would be retracted when not in use, and not take up any additional space, whereas the wall structure has to be moved out of the way when not in use. Depending on the space available, this structure may pose a challenge in optimizing but still be effective in reducing wind speed, and also being smaller in size, easily be stored.

Additional Resources

Only the large covers require additional resources. They would require equipment such as forklifts or trucks to move equipment, additional power requirements, modifications to the wind tunnel, and locking mechanisms among others to be safe and functional for its intended purpose. This drives up the design cost due to the complexity. Additional considerations have to be taken for those designs, and become challenging due to the time constraints of this project.

Appendix B – Concept Selection for Single Fan Covers

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This section elaborates on the development of the single inlet covers design. Six different designs were considered when developing the initial concepts. Some key features of each design are highlighted in the proceeding sections, followed by a decision matrix to choose the optimal design.

Flat Cover

The flat cover is a simple design. The cover sits flush with the wind tunnel, with an opening in the front to allow the motor assembly to pass through. Figure 1 shows the flat cover concept.

Figure 1. Flat cover concept

The design sits flush with the wind tunnel and does not have any protruding geometries that extend over the engine and mount, resulting in a minimal amount of material required. Minimal material is beneficial for the technicians, as a lighter design would be easier to handle. The covers do not completely block all wind due to the cut out in the front; therefore, some debris will enter the tunnel. This design is relatively simple, which might make it easier to implement. Metal, and light polymers, will be considered for this design.

Dome Cover

The domed cover is similar to the flat cover except that it bowls outwards to be able to accommodate the fan motor assembly protruding from the wind tunnel. This cover would be large enough to encompass the entire inlet. An initial concept is shown in Figure 2.

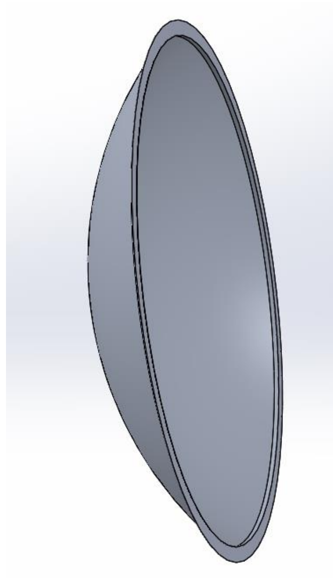

Figure 2. Dome cover concept

Similar to the flat cover, the dome cover could be made using different material combinations, however the dome results in more required material and a higher weight. A key difference in this concept is that it fully covers the fan inlet, which prevents any sort of foreign object debris (FOD) and other debris from entering the wind tunnel. The one main drawback with this design is that it is slightly larger than the flat cover, making it heavier and more difficult for the technicians to lift. Some form of handles or grips will have to be designed to aid with handling of the covers. These covers shield the entirety of the inlets, which may result in undesirably high loads on the wind tunnel.

Canvas Cover

Another viable solution for this problem is creating a cover out of flexible material, such as canvas. It allows the cover to be pliable and shape around the engine mount and cable. Compared to a rigid plastic or metal cover. The canvas cover has the potential to be much lighter than a metal or plastic cover of similar size. A concept is shown in Figure 3.

Figure 3. Canvas cover concept

Several covers could be folded to store in the cherry picker that would hoist them up to onto the wind tunnel. Being a lighter option, the covers would be easier to handle under gusty wind conditions, and do not pose as much of a safety hazard if one of them fall from the cherry picker. This minimizes the possibility of the wind tunnel sustaining damage from impact if one of these covers were to fall.

The canvas cover has the option to cover the entire fan inlet on the face of the tunnel, or allow a portion of the electric cable to protrude from the cover. The cover could wrap around the cable, adding additional security of the cover from shifting around due to the wind, while still minimizing exposure of the wind and elements from entering the tunnel.

The idea is similar to that of an aircraft engine cover, where the material is draped to cover the inlet of the turbine engine. The engine cover is secured using either friction, lacing, or a latching mechanism. An example of an engine cover for a GENX engine which is shown in Figure 4.

Figure 4. Aviation engine cover for GENX engine *[1]*

The flexible fabric cover allows the intricate shapes of the fan inlets and motor to be covered completely and securely while maintaining a light composition.

Louvered Cover (Horizontal)

The louvered cover is designed to meet the allowable cover area requirements while preventing debris and precipitation from entering the fan inlets. Unlike the previously mentioned covers, where the wind and precipitation could blow straight through the openings, these horizontally oriented louvers would be angled such that that water is blocked and run off the wind tunnel rather than into the tunnel. Wind would still be able to flow through the slits between louvers, however, the air entering the tunnel would be slowed down due to the change in direction. Figure 5 shows a concept design for the horizontal louvered cover.

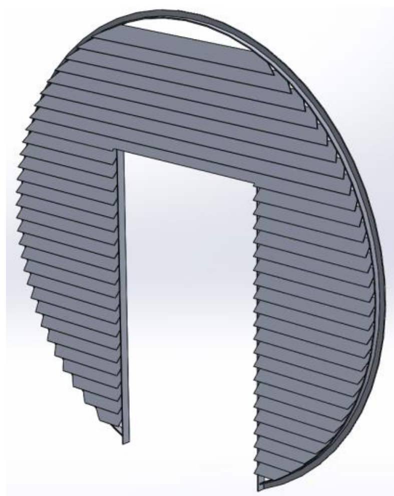

Figure 5. Horizontal louvered cover

The required size and spacing of the louvers is based on how much wind is allowed to be blocked. Due to the fan motor and cables, the cover needs to be fabricated in such a way that it fits around these protrusions securely. This may result in a complex design which will be heavy and cost much more that a simpler design, such as the flat cover.

Louvered Cover (Radial)

Radial louvered cover is a similar idea to the horizontal louvered cover, however the louvers run radially around the covers center, much like a turbine. The concept is shown in Figure 6.

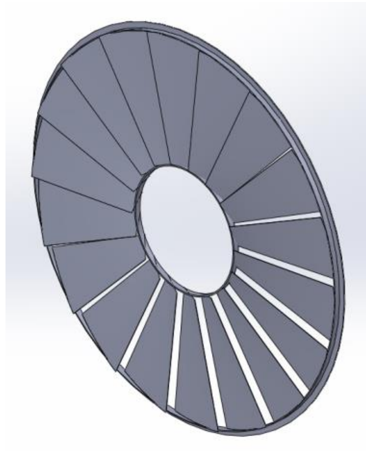

Figure 6. Radial Louver cover

Like the horizontal louvered covers, these covers allow wind through and possibly reduce the winds speed. However, they may not deflect water and debris as efficiently, due to the orientation of the blades. If all louvers are oriented the same way around the cover, some of the louvers deflect water while the opposing louvers let more water in. Due to this, the louvers would likely need to be designed and oriented in such a way that they change orientation to deflect water at all sections. This results in a complex design that may not perform as well as its horizontal counterpart.

90-Degree Deflector

Like the louvered covers, the 90-degree deflector is based off the principle of deflecting debris and precipitation, shown in Figure 7.

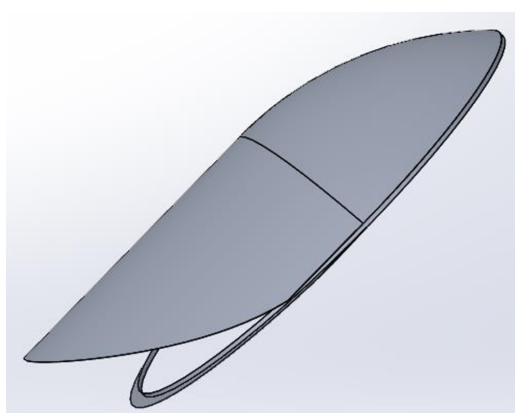

Figure 7. Deflector cover

Instead of an opening down the middle to allow for the motor and cable to stick through the cover, the 90-degree deflector extends beyond the cable and rest overtop of the motor-cable assembly. The bottom of the deflector would remain open to allow for the necessary wind to enter. A drawback of this design is it is larger to accommodate for the protruding motor. As a result, installing may be awkward and strenuous, as the workers would be forced to reach around the cover to secure it.

Metrics for Concept Screening and Weighted Decision Matrix

There are several metrics that were generated based on the client needs. These metrics are used to determine the validity of each cover design, and to compare the covers to one another. Each metric is placed in a table where they will be used to compare the different cover designs.

Wind loading on rail

The loading on the wind tunnel rails is a result of the wind pressure that acts on the tunnel. Any additional surface area, as a result of the covers, will cause an increase of load on the rails. The chocks must not fail, and must prevent the wind tunnel from moving. Failure of the chocks could potentially damage equipment and pose a safety hazard to those working on site. The covers must therefore be designed in such a way to not exceed the maximum value of the loading on the chocks.

Weight

Since the covers will be manually lifted and handled by technicians they must be light enough to comfortably lift onto the cherry picker and install them onto the face of the wind tunnel. A heavy design prevents the workers from handling the covers comfortably. The covers should be less than 25 lbs so that the workers may install them safely and comfortably.

Time to install

Time to install is important due to the sensitivity of weather conditions that engine testing must be conducted. The clients gave a maximum time for all covers to be installed to be 2 hours. Ideally, the covers should be installed in less than this given time limit.

Ease of installation

Ease of installation incorporates the time it takes to install and uninstall the fan covers. The method in which the covers are attached must be quick enough to not take significant time, and should be easy to install when technicians are wearing winter clothing. This ties in with the target specification of a less than 2 hour installation or uninstallation process.

Cost

Even though an exact qualitative value was not given by the clients, the cover should meet all the other target specifications, and then the overall cost can be compared for different designs that meet all of the requirements. If two cover designs both serve their intended purpose, but one is less expensive than the other, then the cover that is the least expensive will be more favourable.

Blocks precipitation and debris

The amount a cover is able to block water and debris will be determined by the size of the openings in the cover, and what geometry the covers possess. The covers should be large enough to reduce the precipitation and other debris that enters the tunnel, and provide more comfortable working conditions for the workers.

Secure

The covers must be able to withstand large wind gusts, and must stay on regardless of weather conditions. This ensures that they are safe for the technicians when working around or inside the tunnel, and safe for the others in the vicinity of the airport, such as other aircraft taking off on the runways and other workers on the airport grounds. The securing method must keep the covers in place and not yield under the maximum gust loads of 119 km/hr.

Fatigue life

The fatigue life of the covers determine how long the covers can last and how often they must be replaced. With the covers being installed and uninstalled frequently, there will be some wear and tear on the attachments. The material used determines how robust the covers will be under various weather conditions. From the target specifications, the covers should last 15 years as the ideal value, and 10 years as the marginal value.

Portable

The covers should be portable to avoid any obstruction during wind tunnel testing. This encompasses the movement of the covers onto the cherry picker and being hoisted onto the tunnel, stored when not in use, and how easy it is for the workers to move the covers from point to point. The relative size and weight of the covers influence this metric. This ties to the time to install target specification, where increasing the portability would help decrease the time taken to install the covers. Ideally multiple covers would be moved all at once to save time.

Easy to clean

If the covers are made of several moving parts it may be more difficult to clean if water, snow, or debris get into the working mechanisms of the cover. Removal of any contaminants should be easy to ensure proper working order of the covers. The cover must be cleaned with tools on site, and ties to the ease of cleaning target specification.

Wind speed

The wind speed should be reduced when the covers are installed in order to provide more comfortable working conditions for the workers. This is important, as it relates to how much pressure the tunnel can withstand with the covers on, which must not exceed the loading on the rail locking mechanism. This is also important, as the problem statement discusses the adverse working conditions experienced by the workers due to the winds passing through the fan inlets on the face on of the tunnel. The ideal target specification is 0 RPM of the fan blades, with 20 RPM being a marginal value that would be considered a successful design.

Metric Weighting

Comparing the metrics show which criteria are more important to consider. This determines the highest scoring criteria when analyzing and comparing the three concepts. Each metric ID is compared against the rest of metrics and the one deemed more important takes the spot in TABLE I.

TABLE I

COMPARISON OF WEIGHTS OF EACH METRIC

		Loading on rail	Weight	Time to install	Ease of Installation	Cost	Blocks water/debris	Secure	Fatigue Life	Portable	Easy to Clean	Wind speed	
Metric	**ID**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Score**
Loading on rail chocks	**A**		A	A	A	A	A	G	A	A	A	A	9
Weight	**B**			B	D	B	F	G	B	B	B	K	5
Time to install	**C**				D	C	F	G	C	C	C	K	4
Ease of Installation	**D**					D	F	G	D	D	D	K	6
Cost	**E**						F	G	H	I	E	K	1
Blocks water/debris	**F**							G	F	F	F	K	7
Secure	**G**								G	G	G	G	10
Fatigue Life	**H**									I	H	K	2
Portable	**I**										I	K	3
Easy to Clean	**J**											K	0
Wind speed through tunnel	**K**												8

From the weighting of the criteria, the top three that have the most significant impact on the design are: how secure the cover is on to the face of the wind tunnel, the loading on the rail chocks, and the wind speed passing through the wind tunnel.

The weights of each criteria are shown in TABLE II. The weights were adjusted by adding 1 to each criteria's score, to avoid having a score of zero. The weighting is then determined by taking the adjusted score of each criteria, and dividing by the total score of all of the criteria. This determines the relative weights of each criteria to one another, and shows which criteria has a larger impact on the requirements of the project.

TABLE II

WEIGHTS OF EACH CRITERIA

Metric	ID	Score	Adjusted	Weighting	Percentage
Loading on rail	A	9	10	0.1515	15.15%
Weight	B	5	6	0.0909	9.09%
Time to install	C	4	5	0.0758	7.58%
Ease of Installation	D	6	7	0.1061	10.61%
Cost	E	1	2	0.0303	3.03%
Blocks water/debris	F	7	8	0.1212	12.12%
Secure	G	10	11	0.1667	16.67%
Fatigue Life	H	2	3	0.0455	4.55%
Portable	I	3	4	0.0606	6.06%
Easy to Clean	J	0	1	0.0152	1.52%
Wind speed through tunnel	K	8	9	0.1364	13.64%
Sum of Adjusted Scores		-	66	-	

Concept Screening

Using the criteria mentioned in 'Metrics for Concept Screening and Weighted Decision Matrix' to compare each single fan inlet conceptual design, the covers can be ranked based on suitability for the application. The top three concepts will be chosen for the weighted decision matrix to evaluate which one is the most ideal design. Using the flat cover as a reference, the cover designs are ranked as shown in TABLE III.

TABLE III

CONCEPT SCREENING SINGLE FAN COVERS

Metric	Flat Cover	Dome Cover	Canvas Cover	Louvered Cover Horizontal	Louvered Cover Radial	90 Degree Deflector
Loading on rail	0	0	0	+	0	+
Weight	0	-	+	-	-	-
Time to install	0	0	-	0	0	0
Ease of Installation	0	0	+	0	0	0
Cost	0	-	+	-	-	-
Blocks water/debris	0	0	0	+	0	+
Secure	0	0	-	0	0	0
Fatigue Life	0	0	+	-	-	0
Portable	0	0	+	-	-	-
Easy to Clean	0	-	-	0	0	-
Wind speed through tunnel (windmilling)	0	0	0	+	+	0
Number of "+"	0	0	5	3	1	2
Number of "-"	0	3	3	4	4	4
Total Score	0	-3	2	-1	-3	-2
Ranking	2	5	1	3	5	4

As shown in TABLE III, the resultant ranking due to the prescribed scoring conclude that the canvas cover, the flat cover, and the horizontal louvered cover are the most ideal. These three covers are carried forward to be further analyzed.

Final Concept Decision Matrix

With the three concepts determined and the weighted values of the metrics assigned, a weighted decision matrix is used to compare the concepts to determine the optimum solution. Each concept is scored from 3 to 1. A score of 3 is given to the concept that performs exceptionally well in the given criteria, a score of 2 is given if the concept performs adequately well in the criteria, and a 1 is assigned if the concept performs poorly in the criteria. This rank is then multiplied by the weight (previously determined) for each criterion and then summed up with the concept obtaining the highest total being the better concept. The results of this process is shown in TABLE IV.

TABLE IV

WEIGHTED DECISION MATRIX FOR 3 SCREENED CONCEPTS

			Flat Cover		Canvas Cover		Louvered Cover	
	Criteria	Weight	Ranking	Score	Ranking	Score	Ranking	Score
A	Loading on rail	0.1515	2	0.3030	2	0.3030	3	0.4545
B	Weight	0.0909	2	0.1818	3	0.2727	1	0.0909
C	Time to install	0.0758	3	0.2273	2	0.1515	3	0.2273
D	Ease of Installation	0.1061	2	0.2121	3	0.3182	1	0.1061
E	Cost	0.0303	2	0.0606	3	0.0909	1	0.0303
F	Blocks water/debris	0.1212	1	0.1212	2	0.2424	3	0.3636
G	Secure	0.1667	3	0.5000	1	0.1667	2	0.3333
H	Fatigue Life	0.0455	3	0.1364	3	0.1364	3	0.1364
I	Portable	0.0606	2	0.1212	3	0.1818	1	0.0606
J	Easy to Clean	0.0152	3	0.0455	1	0.0152	2	0.0303
K	Wind speed through tunnel	0.1364	3	0.4091	3	0.4091	2	0.2727
Total		1.00	-	2.32	-	2.29	-	2.11

As seen in TABLE IV, the Flat Cover concept received the highest score, however, the Canvas Cover scored only 0.03 below the Flat Cover; this score is too close to be certain of an optimal solution. To re-evaluate this scoring, the decision matrix must be remade, comparing only the flat cover and the canvas cover. These covers are ranked either 2 for the concept which is better or 1 for the concept which is worse. The results of this second weighted decision matrix are shown in TABLE V.

TABLE V

WEIGHTED DECISION MATRIX FOR FLAT AND CANVAS COVER

			Flat Cover		Canvas Cover	
	Criteria	Weight	Ranking	Score	Ranking	Score
A	Loading on rail	0.1515	2	0.3030	2	0.3030
B	Weight	0.0909	1	0.0909	2	0.1818
C	Time to install	0.0758	2	0.1515	1	0.0758
D	Ease of Installation	0.1061	1	0.1061	2	0.2121
E	Cost	0.0303	1	0.0303	2	0.0606
F	Blocks water/debris	0.1212	1	0.1212	2	0.2424
G	Secure	0.1667	2	0.3333	1	0.1667
H	Fatigue Life	0.0455	2	0.0909	2	0.0909
I	Portable	0.0606	1	0.0606	2	0.1212
J	Easy to Clean	0.0152	2	0.0303	1	0.0152
K	Wind speed through tunnel	0.1364	2	0.2727	2	0.2727
Total		1.00	-	1.59	-	1.74

From this decision matrix, the Canvas Cover now won by 0.15 which is determined to be a large enough margin to proceed with this concept as the final design. Optimization, method of securing, and final material selection of the covers will be made to make the most optimal cover design possible.

References

[1] King: Bag and Manufacturing Company, [Online]. Available: http://kingbag.com/aviation/. [Accessed 22 October 2018].

Appendix C – Wind Load

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This section details the wind loading from the max allowable load on the wind tunnel section. The following are calculations that are used for the preliminary design of the wind tunnel covers. The objective of these calculations is to determine the maximum frontal area of the inlet covers such that the force of wind does not cause the wind tunnel to move.

Wind Profile

The maximum gust speed was found using Environment Canada reports of Winnipeg's weather from 1978 to 2018. The maximum gust speed recorded within this period is 119 km/hr [1]. This number is used for all wind load calculations.

Although 119 km/hr is the maximum recorded gust speed, wind does not have a uniform profile, and therefore the value is adjusted. The profile of wind speed follows a gradient much like the one shown in Figure 1.

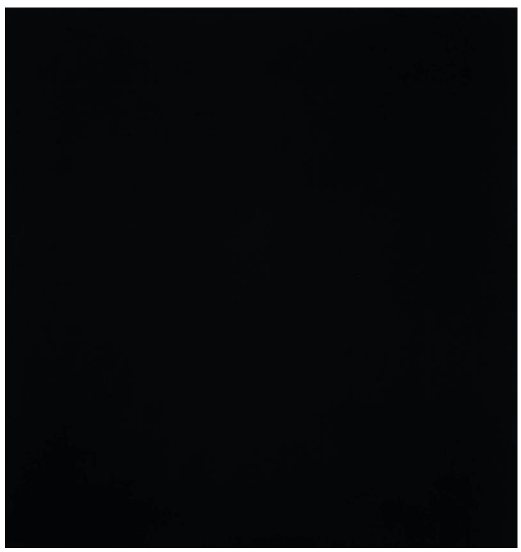

Figure 1. Wind speed velocity gradient *[2]*

This gradient can be calculated using the following formula:

$$v_2 = v_1 \cdot \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)} \quad (1)$$

Where z_0 is the roughness length, v_1 the reference wind speed (119 km/h), $h_1$is the height of the reference wind speed, and v_2 is the wind speed to be calculated at the height h_2. The roughness length is determined using a table of roughness class and lengths, such as the one shown in TABLE I. Given the land cover at GE TRDC, a roughness class of 1 ($z_0 = 0.03$) was deemed the most appropriate.

TABLE I

ROUGHNESS COEFFICIANT FOR DIFFERENT LAND TYPES *[3]*

Roughness Class	Roughness Length z_0	Land Cover Type
0	0.0002 m	Water surfaces: seas and Lakes
0.5	0.0024 m	Open terrain with smooth surface, e.g. concrete, airport runways, mown grass etc.
1	0.03 m	Open agricultural land without fences and hedges; maybe some far apart buildings and very gentle hills
1.5	0.055 m	Agricultural land with a few buildings and 8 m high hedges separated by more than 1 km
2	0.1 m	Agricultural land with a few buildings and 8 m high hedges separated by approx. 500 m
2.5	0.2 m	Agricultural land with many trees, bushes and plants, or 8 m high hedges separated by approx. 250 m
3	0.4 m	Towns, villages, agricultural land with many or high hedges, forests and rough and uneven terrain
3.5	0.6 m	Large towns with high buildings
4	1.6 m	Large cities with high buildings and skyscrapers

Using Eq. (1), data points are calculated at various heights to create a wind profile. The Winnipeg airport measures its wind speed at a height of approximately 10m (33ft); therefore, 10m is the reference height. TABLE II below shows the wind speeds at different heights. The wind tunnel has a wall height of 28ft, and sits approximately 6ft off the ground, totaling a height of 34ft from the ground.

TABLE II

WIND SPEED AT DIFFERENT ELEVATIONS

h [ft]	h [m]	v [km/h]	[mph]
2	0.61	61.69	38.56
4	1.22	75.89	47.43
6	1.83	84.20	52.62
8	2.44	90.09	56.31
10	3.05	94.66	59.16
12	3.66	98.40	61.50
14	4.27	101.55	63.47
16	4.88	104.29	65.18
18	5.49	106.70	66.69
20	6.10	108.86	68.04
22	6.71	110.81	69.26
24	7.31	112.59	70.37
26	7.92	114.23	71.40
28	8.53	115.75	72.35
30	9.14	117.17	73.23
32	9.75	118.49	74.05
33	**10**	**119**	**74.45**
34	10.36	119.73	74.83

The resultant wind speed gradient was then plotted using excel and is shown in Figure 2 from 0.61 to 10.36 meters.

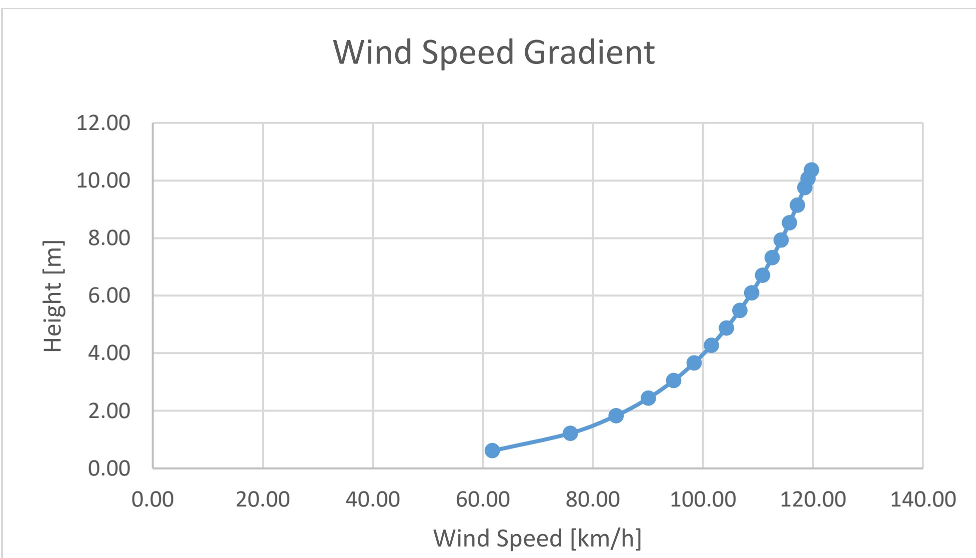

Figure 2. Plotted wind speed gradient

Wind Load

The wind tunnel has a frontal inlet area of 39ft x 28ft, which is 1100ft^2. Additional structures on the wind tunnel, including a water tank, make up approximately 400ft^2, giving a total frontal surface area of 1500ft^2. The fan inlets have a diameter of 8ft, resulting in an area of 50ft^2 for each of the 11 inlets, totaling 550ft^2. Subtracting the area of the open inlets from the total area, the effective frontal area of the wind tunnel without covers is 950ft^2.

The percent of area of the fan inlets that can be covered is based on the resultant force on the wind tunnel due to wind pressure. The maximum allowable force that can be applied to the tunnel is calculated from the holding force of the rail locking system, or chocks. Each chock can hold up to 6,000 lbs. Using a factor of safety of 1.5, as prescribed by the client, the maximum allowable force than can be applied is calculated using Eq. (2).

$$F_{all} = \frac{F_{max}}{FOS} = \frac{6000 \cdot C_n}{1.5} \tag{2}$$

Where C_n is the number of chocks.

Initially, the number of chocks available for use was six, resulting in a maximum allowable force of 24,000 lbf. To calculate the wind pressure, Bernoulli's principle may be utilized for external flow as seen in the following equation:

$$\frac{P}{\rho} + \frac{1}{2}V^2 + gz = \text{Constant} \tag{3}$$

Where P is the pressure, V is the wind velocity in mph and ρ is the air density in slug/ft^3, gz combines the gravitational constant and change in height to make up the potential energy term. The highest loading condition occurs when the fan inlets are fully covered due to the area in contact with the wind. Neglecting the potential energy term and considering the entire face of the wind tunnel stops the wind, then Eq. (2) can be simplified to Eq. (4).

$$P = \frac{1}{2}\rho V^2 \tag{4}$$

The highest density occurs at the lowest operating temperature assumed to be -40°C. The density can be determined by using a simplified version of the ideal gas law as seen in Eq. (5):

$$\rho = \frac{P}{RT} \tag{5}$$

Where P is the ambient air pressure taken to be in standard atmospheric conditions, R is the specific gas constant for air, and T is the temperature of the ambient air taken at -40°C. Inputting the known values, the air density at -40°C is calculated to be 0.00294 slug/ft^3, where the units for a slug is lbf·s^2/ft. Inputting the density into Eq.(4) and converting for a velocity in mph:

$$P\left[\frac{\text{lbf}}{\text{ft}^2}\right] = \frac{1}{2}\left(0.00294\left[\frac{\text{lbf}\cdot\text{s}^2/\text{ft}}{\text{ft}^3}\right]\right)\cdot\left(1.467\left[\frac{\text{ft/s}}{\text{mph}}\right]\right)^2\cdot \text{V}\ [\text{mph}]^2$$

Which can be simplified to

$$P = 0.00316 \cdot V^2 \tag{6}$$

Where V is the wind velocity in mph. Using the wind pressure, the wind load can be calculated using Eq. (7)

$$F = A_{fS} \cdot P \cdot C_d \tag{7}$$

Where A_{fs} is the frontal surface area of the wind tunnel in ft^2, and C_d is the drag coefficient.

Making an assumption for the drag coefficient of the wind tunnel was difficult due to the shape of the tunnel. A solid cube has a drag coefficient of 1.05, and a cylinder facing downstream has a coefficient of 0.82 [4]. Of these two simple models, the most conservative answer is to choose the one with the larger coefficient, thus resulting in a higher pressure; however, a cube does not accurately represent the profile of the wind tunnel due to the rim surrounding the wind tunnel's inlets. The gusting wind approaching the tunnel is assumed to be turbulent, and therefore, the Reynolds number hovers close to 2,000. Fox and McDonalds Introduction to fluid mechanics [5] describes drag coefficients of select objects when the Reynolds number is above 1,000. Among these objects, an open-faced (facing flow) hemisphere is the most appropriate to represent the wind tunnels rim, as shown in Figure 3. This open hemisphere has a drag coefficient of 1.42 which results in a greater calculated load than if the cube was used, and therefore a greater safety factor.

Figure 3. Drag coefficient for selected objects *[5]*

Allowable Cover Area

The allowable size of the cover is based on the resultant load due to wind. As described in Eq. (7), the force proportionally increases as the area of the covers increase. Due to the nature of the wind gradient, a simple calculation of the area at the maximum allowable load cannot be performed. This is because the wind pressure changes at all points vertically along the tunnel. For this reason, an iterative method is used to determine the maximum possible cover area without exceeding the maximum allowable load.

Using the wind speed gradient previously calculated, TABLE II showing the wind speed at various heights off the ground, the table can be expanded to list the force on the corresponding section of wind tunnel, given a certain cover area. The sum of all forces in each of the 2ft vertical section of the 28ft wind tunnel is the total load on the tunnel. For simplicity, each section of wind tunnel is assumed to possess an equivalent amount of open cover area, being identical for each cover. Recalling that the wind tunnel has a surface area of 950 ft^2 (uncovered) and the inlets take up an area of 550 ft^2, Eq. (8) calculates the total effective area of any given section of the wind tunnel for an arbitrary cover area.

$$A = \frac{(950\ \mathrm{ft}^2 + (550\ \mathrm{ft}^2)\cdot \%C)}{n} \tag{8}$$

Where %C is the percentage all 11 inlets covered, and n is the number of sections used to split up the wind tunnel.

Six Locking Chocks

The number of available chocks that are currently used to secure the wind tunnel is 6. Using Eq. (2), the maximum allowable load with 6 chocks and safety factor of 1.5 is 24,000 lbf. TABLE III below lists the results of the percent the inlets can be covered in order to meet, but not exceed, this allowable load. The wind tunnel sections are broken in 2 ft increments, starting at 6 ft off the ground and going up to 34 ft. The reason for this, is the base of the wind tunnel sits 6 feet off the ground, and has a height of 28 ft. The pressure due to the wind speed is then calculated using Eq. (6). The effective area at the given section is then calculated with Eq. (8), utilizing the current iteration of '% of Inlets Covered'. Finally, the force on the corresponding section of wind tunnel is calculated using Eq. (7), and the forces at each section is summed to get the total force.

Using a wind speed of 119km/h (74 mph) at 10 m (33 ft), and a drag coefficient of 1.42, the percent of the inlets that is allowed to be covered, as not to exceed a total load of 24,000 lbf, is 44.50%.

TABLE III

ALLOWABLE AREA COVERED WITH 6 CHOCKS

Percentage of Inlets Covered		**44.50%**		
Section Height [ft]	Wind Velocity [mph]	Pressure [psf]	Section Area [ft^2]	Force/section [lbf]
6	52.62	8.76	79.65	990.44
8	56.31	10.03	79.65	1133.94
10	59.16	11.07	79.65	1251.93
12	61.50	11.96	79.65	1352.67
14	63.47	12.74	79.65	1440.88
16	65.18	13.43	79.65	1519.55
18	66.69	14.06	79.65	1590.67
20	68.04	14.64	79.65	1655.67
22	69.26	15.17	79.65	1715.59
24	70.37	15.66	79.65	1771.23
26	71.40	16.12	79.65	1823.19
28	72.35	16.55	79.65	1871.97
30	73.23	16.96	79.65	1917.96
32	74.05	17.34	79.65	1961.49
34	74.83	17.71	79.65	2002.82
Total			1194.76	**24000.00**

Eight Locking Chocks

Through discussion with the client it was established that with six locking chocks, a 44.5% allowable percent of inlets covered is not an acceptable value. For this reason, GE Aviation gave permission for the cover area analysis to be re assessed with an additional 2 chocks for each set. With eight chocks in total, the maximum holding force of the chocks increases to 48,000 lbf. Taking into account the factor of safety, the max allowable force is 32,000 lbf.

Using a wind speed of 119km/h (74 mph) at 10 m (33 ft), and a drag coefficient of 1.42, the percent of the inlets that is allowed to be covered, as not to exceed a total load of 32,000 lbf, is 100%, as shown in TABLE IV.

TABLE IV

ALLOWABLE AREA COVERED WITH 8 CHOCKS

Percentage of Inlets Covered		**100%**		
Section Height [ft]	Wind Velocity [mph]	Pressure [psf]	Section Area [ft^2]	Force/section [lbf]
6	52.62	8.76	100.00	1243.48
8	56.31	10.03	100.00	1423.64
10	59.16	11.07	100.00	1571.77
12	61.50	11.96	100.00	1698.25
14	63.47	12.74	100.00	1809.00
16	65.18	13.43	100.00	1907.76
18	66.69	14.06	100.00	1997.06
20	68.04	14.64	100.00	2078.66
22	69.26	15.17	100.00	2153.90
24	70.37	15.66	100.00	2223.74
26	71.40	16.12	100.00	2288.98
28	72.35	16.55	100.00	2350.22
30	73.23	16.96	100.00	2407.97
32	74.05	17.34	100.00	2462.61
34	74.83	17.71	100.00	2514.51
Total			1500.00	**30131.54**

Increasing the percentage of inlets covered to the maximum possible option of 100%, the wind load is found to be 30131.53 lbf. Since this load is lower than the maximum allowable load of 32,000 lbf, it can be considered as an increase to the factor of safety. Dividing the maximum loading force of the chocks without the factor of safety (48,000 lbf) by the resultant force due to wind (30,131.54 lbf) the new factor of safety for the wind tunnel loading is 1.59.

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Appendix D – Cover Material Selection

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When considering the design for the covers, a material was selected to withstand the extreme environmental conditions that the covers may be exposed to. Several different materials are examined in this section, with their advantages and disadvantages stated. A decision matrix to select the optimal material was used in the selection process, with vinyl coated polyester being the ideal candidate for the design.

Nylon

Most types of nylon are hard and come in the form of extrusions. Ripstop nylon is a type of nylon that can be used for parachutes and tents [1]. This type of nylon better suits the application for the canvas cover. Ripstop nylon is significantly lighter than regular nylon. This material has a higher flexibility which allows for more modifications to be added to the fan covers. This type of nylon sacrifices a lot of key nylon characteristics to serve this application. It has a lower strength and is prone to more wear. Ripstop nylon can be water resistant and impermeable to water depending on the grade selected [2]. After long exposure to UV rays from the sun, it begins to degrade. Nylon is relatively light with a density of 1.15 g/cm^3.

Polyester

Known by its brand name Terylene, polyester is a synthetic polyester fibre which has a wide range of uses. The fibre can be found in pillows, clothing, upholstery, sails and seatbelts. These fabrics can be spun and extruded into fibers, which can then be formed into textiles, as shown in the polyester scrim in Figure 1.

Figure *1*. Polyester scrim *[3]*

The scrim is a web like material that takes up the loads that are acting on the material. The scrim is made from a continuous material and forms a mesh like pattern.

Polyester has several advantageous physical properties such as resistance to UV light, its ability to retain its material strength when wet and act as a barrier to moisture [4]. Polyester is crease resistant [5], which benefits the design as the cover will be folded and unfolded several times and also has exceptional dimensional stability. This makes it suitable under the conditions that are experienced at the GE TRDC. In terms of weight, polyester is considerably heavy with a density of 1.38 g/cm^3.

Polyester Vinyl

Vinyl coated polyester is used for various different applications including: covering goods being shipped by freight, aviation engine covers, boat covers, tent tarps and various other applications. The material is composed of polyester scrim, as shown in Figure 1, and a vinyl coating is applied over the scrim and allowed to set.

This vinyl coating can make the material water, mildew and UV resistant depending on the treatment [6]. Since the covers will be outside under all environmental conditions, this may prove beneficial as the material is more likely to protect the motors under a wider range of conditions. The vinyl protects the polyester scrim from the UV rays by either absorbing or reflecting the radiation and prevents deterioration of material properties of the polyester [7].

The material is pliable, which allows it to conform easier to whatever structure it may be covering. The vinyl coated polyester comes in various weights, which provides customization depending on the use of the material. Common weights are 18, 20 and 22 oz/yard^2, with corresponding weighs of 6.3 lbs, 7 lbs and 7.71 lbs for a flat 8-foot diameter circle of this material. The tensile strength of the material varies based on the denier size (thickness of the threads), and how many threads are woven together in the warp (vertical) and weft (horizontal) directions.

The weight of the fabric is of interest to the design, as the covers are installed by hand. Ideally the lightest fabric should be chosen, however the strength of the fabrics must also be considered. Different vendors can are consulted to supply material property information when doing analysis on the covers.

Kevlar

Kevlar is a strong synthetic (aramid) fiber which is used in high impact applications. Aramid fibers have high tensile strengths; Kevlar is no exception, as it possesses a tensile strength to weight ratio 5 times greater than steel [8]. Due to its high tensile strength, Kevlar is used in a wide range of applications such as bullet proof vests, sporting equipment, and foot ware. Aside from a high tensile strength, another benefit that comes with Kevlar is its high Modulus, meaning it does not stretch as much as other fibrous materials under load. However, Kevlar has several drawbacks. One drawback of Kevlar is its flex strength. In industry, flex strength is a fibers ability to retain its strength after being folded in the same location multiple times [9]. The loss of the materials strength during this test strength is called "flex loss". Kevlar experiences flex loss, as do many materials with a high modulus. If Kevlar is used for the covers, the flex loss results in difficulty when attempting to store the covers. Another drawback of Kevlar is its lack of UV resistance. Like most aramids, Kevlar experiences UV degradation when exposed to direct sunlight, and therefore require a coating to prevent fast decomposition of the material [10]. When compared to nylon or polyester, Kevlar has a much higher cost and is heavier, as Kevlar possesses a density of 1.44 g/cm^3.

Concept Scoring and Selection

This section defines and weighs the relevant criteria for the selection of the material cover. Each cover material is then weighted against one another in order for an optimal material to be chosen for the final design.

Criteria Description

Modulus

The materials resistance to elastic deformation. A higher modulus ensures the cover stays taut and secure on the inlet

Breaking Strength

The force that can be withstand by the material before breaking

UV Resistance

The materials ability to resist strength loss as a result of direct exposure to UV Rays

Flex Loss

Strength lost due to folding of the material reputedly in the same location. The higher the flex loss, the faster a material breaks after repetitive folding

Cost

The expected cost of the material.

Weight

The expected weight of the material. The covers must be light enough to carry by hand

Water Resistance

The covers will be exposed to rain and snow throughout the year, and cleaned with water; therefore, the material must be resistant to water damage.

Criteria weighting

Comparing the metrics to one another determines which criteria is more important. This is used to identify the criteria with the highest weight when analyzing and comparing the three concepts. Each metric ID is compared against the rest of metrics and the one deemed more important takes cell in the table.

TABLE I

WEIGHTED DECISION MATRIX FOR COVER MATERIAL

Criteria	ID	A Modulus	B Breaking Strength	C UV Resistance	D Flex Loss	E Cost	F Weight	G Water Resistant	Score
Modulus	**A**		B	C	D	A	A	G	2
Breaking Strength	**B**			C	D	B	B	G	3
UV Resistance	**C**				C	C	C	C	6
Flex Loss	**D**					D	D	G	4
Cost	**E**						F	G	0
Weight	**F**							G	1
Water Resistant	**G**								5

Adjusting the scores and weighing them against one another provides the percent they contribute to the selection of the cover design.

TABLE II

WEIGHTS OF EACH METRIC FOR COVER MATERIAL

Criteria	ID	Score	Adjusted	Weighting	Percentage
Modulus	**A**	2	3	0.1071	10.71%
Breaking Strength	**B**	3	4	0.1429	14.29%
UV Resistance	**C**	6	7	0.2500	25.00%
Flex Loss	**D**	4	5	0.1786	17.86%
Cost	**E**	0	1	0.0357	3.57%
Weight	**F**	1	2	0.0714	7.14%
Water Resistant	**G**	5	6	0.2143	21.43%

Base Material Concept Selection

A decision matric is used to determine which material is ideal for the final design. The scoring of each material is shown in TABLE III.

TABLE III

FINAL SELECTION OF COVER MATERIAL

			PolyVinyl		Kevlar		Nylon		Polyester	
	Criteria	Weight	Ranking	Score	Ranking	Score	Ranking	Score	Ranking	Score
A	Modulus	0.1071	3	0.3214	4	0.4286	1	0.1071	2	0.2143
B	Breaking Strength	0.1429	3	0.4286	4	0.5714	2	0.2857	1	0.1429
C	UV Resistance	0.2500	4	1.0000	1	0.2500	2	0.5000	3	0.7500
D	Flex Loss	0.1786	4	0.7143	2	0.3571	4	0.7143	4	0.7143
E	Cost	0.0357	2	0.0714	1	0.0357	4	0.1429	3	0.1071
F	Weight	0.0714	3	0.2143	2	0.1429	4	0.2857	3	0.2143
G	Water Resistant	0.2143	4	0.8571	3	0.6429	1	0.2143	2	0.4286
Total				3.61	-	2.00	-	2.25	-	2.57

Based on the results from the decision matrix, polyvinyl is the ideal material given the required criteria. For this reason, the final design uses Poly Vinyl Chloride.

Protection Foam

To ensure that the motor and cable are adequately protected, a small piece of foam is used to act as a shield to soften the load applied from the wind pressure pressing the covers against the cable. It also aids in preventing any sharp edges from tearing through the entire cover. When selecting the foam, it is important to find the balance between a foam with a high compressive strength while maintaining a certain firmness to reduce weight and be effective. The foam selected must be able to perform in the entire temperature range without sacrificing desirable characteristics.

Two primary foams were selected to analyze: polyethylene and polyurethane. These were selected due to the commercial availability of these foams. Both foams are used in packaging applications to protect products from damage.

Polyethylene

Polyethylene is a cross-linked type foam with closed cells. This means that it is more rigid and does not allow for any air to pass through [11]. The rigidity of this foam makes it recover its original shape extremely quick after a load is removed. The cross-linked structure of it makes it strong and provides a high tear resistance. This makes it strong in any orientation when stretched out. Polyethylene packaging is generally less shock resistant and can better handle harder impacts applied in localized areas. For the use for the fan inlet covers, polyethylene has the additional benefit of being highly resistant to chemicals and moisture [12]. This prolongs life of the foam block, thus saving costs. Polyethylene foams can come in sheets or planks depending on the thickness necessary for the application and could be easily replaced if needed.

Polyurethane

Polyurethane foam is a softer foam and much more flexible compared to polyethylene. It is an open cell structure allowing air to pass through [11]. This makes it a lighter foam compared to polyethylene. This foam is typically used as crash protection and serves as better protection against spread out impact. Polyurethane has a higher shock absorption due to its elastic properties [11]. This causes it to absorb the shape of the object it is being pressed against and is excellent to wrap around items. The drawback is that it takes a longer time for this foam to recover to its original position. It is typically used to protect items that are more fragile. Due to polyurethane's low abrasion, it is excellent where objects will be sliding in contact around it or have loose fitting [13]. Depending on the type of foam selected, polyurethane can have good environmental qualities. It can withstand high temperature ranges and avoid the growth of mold or mildew [13]. Polyurethane is versatile and is easy to modify to meet different needs.

Foam Selection

The foam selected to use to shield the motor cable is a type of polyurethane. The flexibility allows the foam to fully cover the cable connected to the motor and wrap around to protect from the edges. The elastic properties would help lengthen the life of the foam after experiencing numerous loads. Its environmental capabilities also aid in its maintenance as the same piece of foam can be used year-round. Since its primary purpose is to act as a cushion, it is much more advantageous to use over polyethylene because a high strength is not required, and it has a lower weight.

To meet all the desired specifications, polyfoam is selected. This is a type of polyurethane foam often used for cushions. TABLE IV summarizes the key characteristics of this foam.

TABLE IV

MATERIAL PROPERTIES OF POLYFOAM

Property	Value
Density [lb/ft^3]	1.3
Tensile strength [psi]	14
Tear Strength [ppi]	1.5
Elongation at break [%]	200
Indentation load deflection- 25% [lb]	36
Temperature range	All

Given the way that the foam will be positioned, many of the properties are not a major concern. Each foam block will be 12 inches in height and 30 inches wide. The frontal surface area of the face of the block 360 in^2. Given that the maximum load experienced on a cover is 849.21 lbf, the load scaled down to the foam area is 42.23 lbf. At this load, the foam compresses slightly more than 25% under the maximum load conditions. To compensate, a thicker foam is selected to ensure an adequate amount of protection for the cable.

The foam planks can be purchased through the Foam Factory. The plank thickness selected is 1”, with one full sheet size of 82” x 76” each. Each sheet produces 14 foam planks which is enough for all covers with extra for contingency [14].

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Appendix E – Stress Experienced by Cover Due to Wind Loading

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When installed, the inlet covers will experience a significant amount of force due to the gusting wind. To ensure that the selected material can withstand the applied force, the resulting stress in the cover must be calculated.

The force due to pressure across a certain area is expressed in Eq. 1.

$$F = P \cdot A \tag{2}$$

As described in Appendix C, the wind pressure changes at different elevations; therefore, each cover is split up into four 2' sections, labeled S_3,S_2,S_1, and S_0 as shown in Figure 1.

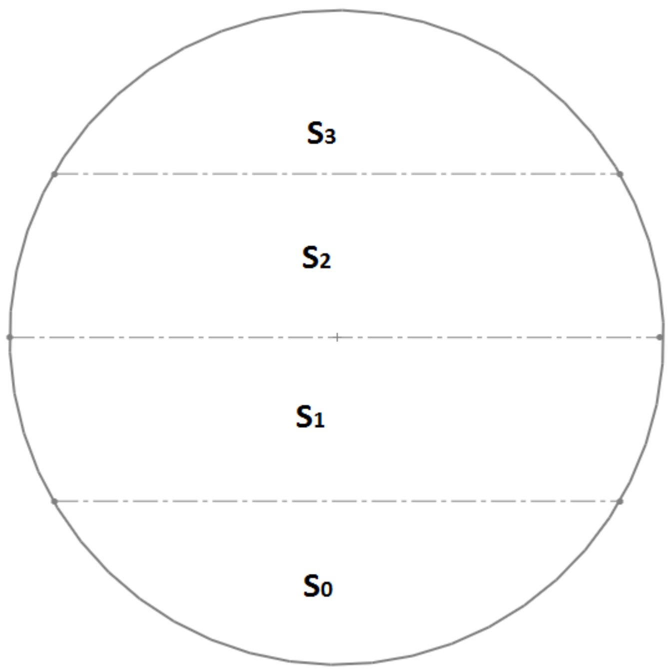

Figure 1. Sectioned areas of wind tunnel inlets

For the most accurate depiction of the force on the cover, the area of each section must be calculated individually. This area will then be multiplied by the pressure of the corresponding section to get the force applied to that specific section. The pressures at different elevations is determined in Appendix C. The sum of forces on all section of the cover is the total force on the cover.

Eq. 3 is used to finds the area of a quarter circle.

$$C = \int_{b_1}^{b_2} \sqrt{a^2 - y^2}\, dy \tag{4}$$

Where a is the circle radius, and y is any arbitrary height which is integrated across the bounds of b_1 and b_2. The integration can be taken at any of the four cover sections to get half the area of the respective section, as shown in Figure 2.

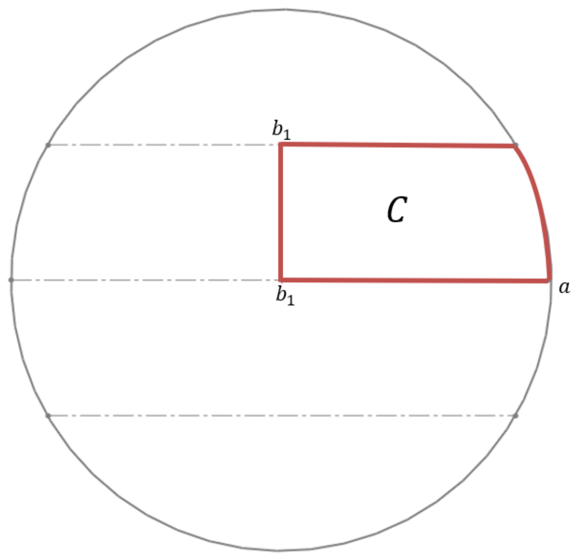

Figure 2. Circle broken into sections

Making use of symmetry about the centre of inlet, the area of each section S_i is calculated using Eq. 5.

$$S_i = 2 \cdot C_i \tag{6}$$

When the area of all four sections of the cover is determined, the total force the cover experiences is calculated using Eq. 7.

$$F = \sum_{i=1}^{i=4} S_i \cdot P_i \tag{8}$$

Where S_i and P_i are section area and pressure respectively. The resulting stress in the covers due to the force of wind is considered as a normal stress. The wind pressure would force the cover inwards and stretch the material, imposing a normal stress on the individual strands of polyester within the fabric. The normal stress induced at each section is calculated using Eq. 9.

$$\sigma = \frac{P}{A} \tag{10}$$

The force across the cover is calculated assuming a 2-D shape with a total area of 50.26 ft^2. The stress caused by this force must be calculated using the total 3-D surface area of the cover, with the assumption that the stress will evenly distribute across the cover. The total 3-D surface area of the cover is 73.97 ft^2.

Using the procedure above, the force and resulting stress for all eleven inlet covers is tabulated in TABLE I.

TABLE I

FORCE, AREA AND STRESS PER SECTION AT VARIOUS HEIGHTS OF WIND TUNNEL

Section Height [ft]	Wind Velocity [mph]	Pressure [psf]	Section Area [ft^2]	Force/section [lbf]	Normal Stress [lbf/ ft^2]
Bottom 4 Fans					
10	59.16	11.07	9.83	169.48	-
12	61.50	11.96	15.31	183.11	-
14	63.47	12.74	15.31	125.23	-
16	65.18	13.43	9.83	132.02	-
Total			**50.28**	**609.84**	**8.24**
Middle 3 Fans					
18	66.69	14.06	9.83	138.21	-
20	68.04	14.64	15.31	224.14	-
22	69.26	15.17	15.31	232.25	-
24	70.37	15.66	9.83	153.94	-
Total			**50.28**	**748.54**	**10.12**
Top 4 Fans					
26	71.40	16.12	9.83	158.30	-
28	72.35	16.55	15.31	253.22	-
30	73.23	16.96	15.31	259.49	-
32	74.05	17.34	9.83	170.28	-
Total			**50.28**	**841.29**	**11.37**

Observing entries from TABLE I above, the covers situated at the highest location of the wind tunnel experience the highest load of 841.29 lbf, while the covers at the midsection and bottom section of the tunnel experience loads of 748.54 lbf and 576.42 lbf respectively. Since all eleven covers are the same size, the covers that experience the highest wind forces are used as the baseline for analyzing the stress the covers will experience. The covers on the top row will experience the highest stress of 11.37 lbf/ft^2. This value is referenced to the tensile strengths of poly vinyl from various vendors from TABLE II.

TABLE II

VINYL COATED POLYESTER FABRIC SPECIFICATIONS

Vendor	Weight of Material [$oz/yard^2$]	Thickness [in]	Tensile Strength [lbf/in^2]		Shear Strength [lbf/in^2]	
			Warp	Weft	Warp	Weft
TMI Inc. [1]	18	0.02	480	500	90	70
	22	0.024	640	595	100	80
Rochford Supply [2]	18	-	444	441	-	-
	22	-	641	595	-	-
Lev-Co [3]	22	-	300	290	100	70
Naizil Coated Fabrics [4] [5]	22	-	425	400	60	50
	18	-	440	410	75	65

The polyvinyl material selected for the covers is 18 oz. from Norwood Tent and Awning, and has a tensile strength of 440 lb/in^2. As stated, the maximum normal stress due to wind the covers will experience is 11.37 lbf/ft^2, therefore there is no risk of the material failing when applied to the maximum possible wind load. The high strength also provides a high safety factor to mitigate tensile failure due to other environmental conditions or loads imposed on the covers.

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Appendix F – Method of Securing Cover to Wind Tunnel

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This section details the method of securing the cover to the wind tunnel, as mentioned in securing method under final design. To ensure the cover is secured, two independent factors must be analyzed. The first method is securing the cover to the fan inlet lip, and the second method is the joining the two halves of the cover slit together. The purpose of the slit in the cover is to accommodate for the power cable protruding from the wind tunnel. When the cover is installed, the cover needs to be secured to the lip of the inlet in such a way that is easy to operate, cost effective, and can be used at all eleven fan inlet locations. Once the cover is secure to the inlet lip the two halves of the slit must be connected behind the power cable.

Securing Method

Several different concepts are considered when determining an optimal method of securing the covers. Four options are presented in this section, including latches, ratchet straps, magnets, and hooks. A short description of each method is provided, along with their benefits and drawbacks; from these descriptions the concepts are compared to one another and ranked. The method with the greatest merit is chosen as the securing method for the final design.

Latch

The latch is a mechanical device that holds two surfaces together using a catch and a lever, as shown in Figure 1. Attached to the lever is some form of bar or hook which locks on to the catch when the lever is compressed. These latches will be placed around the circumference of the cover and hook onto the lip of the fan inlets. Once positioned correctly, the latches are fastened, thus securing the connected portion of the cover.

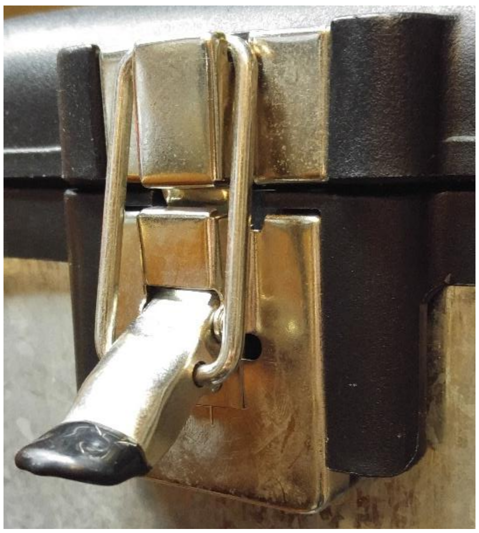

Figure 1. Latch [1]

A list of the benefits and drawbacks of using latches as the covers securing method is listed in TABLE I below.

TABLE I

BENEFITS AND DRAWBACKS OF LATCHES

Benefits	Drawbacks
Easy to secure latches while wearing gloves.	Latch needs a hard surface to push against compress the lever.
If one latch fails, remaining latches keep the cover secured until cover is removed.	Need to be individually positioned and secured, resulting in a long and tedious job.
	Latch points result in stress concentration on the cover material.

Ratchet Strap

A ratchet strap, shown in Figure 2, is a fastener used to tie down and secure heavy equipment. For the ratchet strap to secure the covers, the strap will encircle the circumference of cover through a sewn in sleeve, and act as a drawstring. The ratchet allows the technicians to connect and tighten the two ends of the strap together without the inconsistency and hassle of tying a knot.

Figure 2. Ratchet Strap [1]

A list of the benefits and drawbacks of using a ratchet strap as the securing method is listed in TABLE II.

TABLE II

BENEFITS AND DRAWBACKS OF RATCHET STRAPS

Benefits	Drawbacks
Fast to install, as there is only one location needed to secure the whole cover, the ratchet.	No backup securing mechanism if strap were to break.
Strap provides a uniform force around the entire circumference of the fan inlet when tightened.	Difficult to feed strap through ratchet while wearing gloves.
Rated for thousands of pounds of force.	
Resistant to weather factors such as UV and water damage.	
Ratchet can be shifted along the circumference of the cover for ease of installation, and installed at various locations.	

Magnets

A magnet is an object that creates a magnetic field. The lip if the inlet is made of steel (A572-GR.50) and has strong attraction towards magnets, as the steel contains a large amount of iron (98%) [2]. An appropriate magnet to attach the inlet covers to the wind tunnel is a nickel plated neodymium magnet. These magnets would be inserted in sleeves that surrounds the circumference of the cover such that the magnets attach to the lip around each fan inlet. Each sleeve would have a small zipper or Velcro strip to allow for easy access to the magnet.

A list of the benefits and drawbacks of using magnets to secure the cover is listed in TABLE III.

TABLE III

BENEFITS AND DRAWBACKS OF MAGNETS

Benefits	Drawbacks
Magnets can be repositioned and moved to adjust tautness of cover.	Strong pull force may result in injury if technicians hand gets between wind tunnel and magnet.
	Difficult to remove magnet given required pull force.
	Can get stuck together.
	Magnets demagnetize over time.

Hooks

Hooks are simple curved load bearing beams, used to support or otherwise non-permanently attach two objects or materials together. Like the latch, these hooks would be placed at various locations around the circumference of the inlet and then attach to the inlet lip. What makes this method different from the others is the method of securing the hooks. At the center of the cover is an extendable rod which fits between the face of the fan motor and the inside of the cover. Once the hooks are placed onto the inlet lip, the rod extends, pushing the cover away from the inlet until the cover and hooks are taut and secure. A list of the benefits and drawbacks of using hooks as a securing method is listed in TABLE IV below.

TABLE IV

BENEFITS AND DRAWBACKS OF HOOKS

Benefits	Drawbacks
Fast to uninstall.	If rod breaks, entire cover becomes insecure.
Securing the hooks is done from one location, the rod.	Difficult to align all hooks prior to securing them.
Rod can be extended or compressed to adjust tautness of cover.	Loose swinging hooks could become safety hazards, causing bodily harm.
	Latch points result in stress concentration on the cover material.
	Each hook needs to be individually positioned.

Securing Method Concept Selection

The following is a description of each of the criteria used when ranking and comparing the four securing methods.

Easy to Use

This metric evaluates how easy the device is to use, mainly when gloves are worn.

Weather Proof

This metric is used to evaluate if the design can withstand the predicted weather conditions and incoming debris.

Versatility

This metric evaluates if the design can be easily used and adjusted to work on all eleven inlet locations.

Secure

This metric is used to compare the different design's ability to hold the cover secure to the fan inlets.

Stress Concentration

This metric compares the expected stress concentrations on the cover resulting from the securing method. Designs that secure the cover on point locations result in higher stress concentrations than designs that secure the cover uniformly along its circumference.

Adjustable

This metric compares the adjustability of the covers. Depending on the situation, the cover may need to be pulled tighter or loosened on the inlets. An adjustable securing device allows for greater tolerances in the fabrication and installation of the cover.

Time to install

This metric simply ranks the designs based on a prediction of the time to install or uninstall the cover.

Ease of Replacement

This metric assesses the ease of replacing the securing device upon failure. The securing device experiences higher loads than the rest of the cover which will likely result in failure earlier on. It is beneficial to use a design that can easily be replaced.

Severity of Failure

This metric analyzes whether the cover will remain secure on the inlet, or completely fall off, should the securing device fail. If the design has multiple securing points, it is likely that the cover would remain secure if one point were to fail.

TABLE V lists and ranks the four possible securing methods against the criteria described above. The Latch is used as a reference, and each other design is ranked worse or better in the corresponding categories.

TABLE V

SECURING METHOD

Securing Method				
Criteria	**Latch**	**Ratchet Strap**	**Magnet**	**Hooks**
Easy to Use	0	+	-	0
Weather Proof	0	0	0	0
Versatility	0	+	+	+
Secure	0	+	-	0
Stress Concentration	0	+	0	0
Adjustable	0	+	+	+
Time To install	0	+	0	-
Ease of Replacement	0	+	0	-
Severity of Failure	0	-	0	-
Number of "+"	0	7	2	2
Number of "-"	0	1	3	3
Total Score	0	6	0	-1
Ranking	2	1	3	3

Based on the results, the Ratchet strap is determined to have the highest ranking. For this reason, the inlet covers are designed with the ratchet strap as the primary method of securing.

Rejoining Method

A variety of concepts were examined when choosing a method of rejoining the two halves of the cover. A short description of each method is provided below, along with their benefits and drawbacks. The different methods are then ranked in a similar fashion as the securing method. The concept with the most benefit is chosen as the joining method for the final design.

Zipper

One method for rejoining the cover slit is a zipper. The strips of teeth would be sewn along the length of the open edges of the slit. The two halves of the slit would be brought together and the slider of the zipper would join the zipper teeth. The benefits and drawbacks of using a zipper to rejoin the cover slit is listed below in TABLE VI.

TABLE VI

BENEFITS AND DRAWBACKS OF ZIPPERS

Benefits	Drawbacks
Easy and fast to use.	Zipper could freeze during the winter, making installation or removal of the cover difficult
Uniform stress distribution along zipper	The zipper is not an easy component to replace if it broke

Velcro

A joining method using Velcro would likely involve a flap that runs parallel to the slit. The flap would have a strip of 'Hooked' Velcro running along its length. This flap would extend over the cover's slit, connecting to the second piece of 'Looped' Velcro. Figure 3 shows the two halves of the Velcro, where the top black-portion possesses the 'hooks', and the bottom white-portion possesses the 'loops'.

Figure 3. Velcro [1]

The benefits and drawbacks of using Velcro to rejoin the cover slit is listed below in TABLE VII.

TABLE VII

BENEFITS AND DRAWBACKS OF VELCRO

Benefits	Drawbacks
Easy and fast to use	A strong wind could potentially detach the Velcro
Does not require a significant amount of precision.	Velcro may get packed with ice, snow, or debris, making the connection weak and ineffective.
This method may be used as a secondary cover to shield other joining methods	

D-rings and Clips

A series of clips, such as carabiners, may be installed in series along one half of the slit. Along the opposing side of the slit, in line with the hooks, would be a series of D-Rings or grommets. When joining the two halves of the cover slit, the hooks would lock onto its corresponding ring. The clips would be attached to the covers via adjustable straps to allow for adjustments and better alignment of the slit. A carabiner clip is shown in Figure 4 below.

Figure 4. D-ring and Clip [1]

The benefits and drawbacks of using D-rings and Clips to rejoin the cover slit is listed below in TABLE VIII.

TABLE VIII

BENEFITS AND DRAWBACKS OF D-RINGS AND CLIPS

Benefits	Drawbacks
Can perform effectively in all weather conditions.	Long installation time, as each clip needs to be individually hooked.
Components can be easily replaced.	Stress concentration develops on the cover at the locations of the attached clips.
Adjustable straps allow for readjustment of the slit after installation to better secure the cover.	

Bungee cords

Bungee cords can be used like stretchable straps that allow for constant tension between two surfaces. Like the carabiner clip method, a D-ring, or other joining source, would be positioned in line with the opposing bungee cords. The bungee cord would hook/lock onto its respective D-ring, thus securing the two halves of the slit.

Figure 5. Bungee Cord [1]

The benefits and drawbacks of using bungee cords to rejoin the cover slit is listed below in TABLE IX.

TABLE IX

BENEFITS AND DRAWBACKS OF RATCHET STRAPS

Benefits	Drawbacks
The bungee cords are easy and inexpensive to replace.	Under load, bungees experience creep and elongate overtime.
Provide constant force, holding edges of slit together.	Cover becomes unsecure when bungees elongate.
	Long installation time; each bungee needs to be individually hooked.

Strap Clamp

This method of joining the two halves of the slit would require a series of straps secured at one end to one half of the slit, and a series of strap clamps attached to the other side of the slit. The straps and clamps would be aligned in parallel, and the strap would be fed through the clamp and tightened to secure the two halved of the slit.

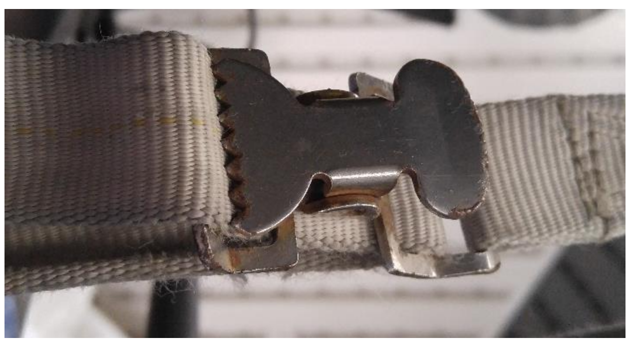

Figure 6. Spring Loaded Strap Clamp [1]

The benefits and drawbacks of using strap clamps to rejoin the cover slit is listed below in TABLE X.

TABLE X

BENEFITS AND DRAWBACKS OF A STRAP CLAMP

Benefits	Drawbacks
Straps can be adjusted within the clamp, allowing for the slit to be tightened or loosened if needed.	Long time to install; each strap must be individually fed through the clamp while installing.
	Hard to use while wearing gloves.

Rejoining Method Concept Selection

TABLE XI lists and ranks the five different joining methods for the cover slit. The Zipper is used as a reference, and each other design is ranked either worse or better in the corresponding categories. The criteria for the joining method shares the same description as the securing method, except for Versatility as it is not considered a determining requirement for the joining method.

TABLE XI

REJOINING METHOD

Joining Method					
Criteria	**Zipper**	**Velcro**	**Carabiner**	**Bungee Cord**	**Strap Clamp**
Easy to Use	0	0	0	0	-
Weather Proof	0	-	+	0	+
Secure	0	-	0	-	0
Stress Concentration	0	0	-	-	-
Adjustable	0	0	+	0	+
Time To install	0	0	-	-	-
Ease of Replacement	0	0	+	+	0
Severity of Failure	0	0	+	+	+
Number of "+"	0	0	4	2	3
Number of "-"	0	2	2	3	3
Total Score	0	-2	2	-1	0
Ranking	2	4	1	3	2

From the results, the carabiner is determined to be the best option, however, all five options are close in ranking and would be valid alternatives if needed.

References

[1] E. Barnson, *"Personally taken photos",* Winnipeg: Design Eng.,Univ Manitoba, 2018.

[2] "MatWeb," [Online]. Available: http://matweb.com/search/datasheet.aspx?matguid=9ced5dc901c54bd1aef19403d0385d7f&ckck=1. [Accessed 22 November 2018].

Appendix G – List of Vendors

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List of Tables

This appendix outlines the vendors that are capable to manufacturing the covers, along with other vendors that sell materials required for securing and installing the covers.

Cover Material

For the cover material itself, there are four possible vendors: King Bag in Cincinnati Ohio, Norwood Tent and Awning in Winnipeg, Manitoba, Murray Tent and Awning in Winnipeg, Manitoba, and Winkler Canvas in Winkler, Manitoba. These companies specialize in making tents, aviation covers, and other projects using textiles. These companies provided estimated quotes for the cover materials, available materials for use, and other particulars related to manufacturing the covers, as shown in TABLE I.

TABLE I

VENDOR LIST COVER MATERIAL

	King Bag and Manufacturing Co.	Norwood Tent and Awning	Murray Tent and Awning	Winkler Canvas
Material	22 oz. FR blue or gray fabric (-55 deg. F cold crack conformance)	18 oz. Polyester Vinyl	40 oz. vinyl material (-40°C cold crack resistance)	22 oz. PVC fabric (-45℃ cold crack resistance)
Estimated Cost	$432.10 individual/ $4753.10 USD total	$290.00 CAD individual $3604.70 CAD total (taxes included)	$295.00 CAD individual/ $3245.00 CAD total	$225.00 CAD individual/ $2475.00 CAD total
Vendor Location	Cincinnati, OH, USA	Winnipeg, MB, Canada	Winnipeg, MB, Canada	Winkler, MB, Canada
Available Materials	D-rings, spring snaps, strap locks	D-rings, spring snaps, strap locks	N/A	N/A
Website	http://kingbag.com/aviation/	http://www.norwoodtentandawning.com/	http://www.murraytentandawning.com/	https://www.winklercanvas.com/
Other Particulars	Lead time: 8-10 weeks	50% deposit, balance on completion	N/A	Lead time: 1-2 weeks from order with free delivery

Ratchet Straps

Ratchet straps were selected that had were long enough to feed through the cover sleeves, and provide enough cinching forces to keep the covers on the wind tunnel under maximum gust conditions. The following table shows three ratchet straps considered for the design.

TABLE II

RATCHET STRAP VENDOR LIST

Vendor	Home Depot [1]	Uline [2]	Ratchet Strap USA [3]
Ratchet Strap	2" wide x 27' long, 3,333 lb working load limit	2" wide x 27' long, 1,600 lb working load limit	2" wide x 30' long, 1,466 lb working load limit
Estimated Cost [CAD]	$30.29	$35.00	$15.29
Vendor Location	Winnipeg, MB	Online	Online
Type	2-piece	Endless (1-piece)	2-piece

Bar Clamps and Magnets

A bar clamp will be used during the installation process to temporarily hold the cover in place. Three clamps would be ideal to hold the cover to the wind tunnel, and two to hold the folded cover in place at the bottom. Two bar clamps were considered, with the rated specifications shown below.

TABLE III

BAR CLAMP VENDORS

Vendor	Acklands Grainger [4]	Princess Auto [5]
Bar Clamp	6" Bar Clamp	6" Bar Clamp
Clamping Strength	445 lbs	770 lbs
Estimated Cost [CAD]	$30.48	$29.99
Vendor Location	Online	Winnipeg, MB

Magnets are also considered to help install the covers. Magnets with a pull force of at least 20 lbs were considered to ensure that they would be effective when installing. The magnets considered are in TABLE *IV*.

TABLE IV

SPECIFICATIONS OF DISC MAGNET

Vendor	Acklands Grainger [6]	K&J Magnetics,Inc. [7]
Material	Sintered Neodymium Disc	Neodymium cylinder
Thickness	0.25”	0.75”
Diameter	1”	0.5625”
Pull Force	19.4 lbs	20.30 lbs
Cost	$4.37	$5.47
Weight	0.08 lbs	0.05lbs
Location	Winnipeg, MB	Online

References

[1] Home Depot, "HUSKY 27 ft. x 2 inch Heavy Duty Ratchet Tie-Down with J hook 1PK," [Online]. Available: https://www.homedepot.ca/en/home/p.27-ft-x-2-inch-heavy-duty-ratchet-tie-down-with-j-hook-1pk.1001034725.html. [Accessed 1 December 2018].

[2] "Ratchet Tie Downs," ULINE, [Online]. Available: https://www.uline.ca/Product/Detail/H-3342/Dock-Equipment/Ratchet-Tie-Downs-Endless-2-x-27-5000-lb-Capacity?pricode=YG064&gadtype=pla&id=H-3342&gclid=Cj0KCQiA_4jgBRDhARIsADezXciAKAK0a-N0LLF_xSx9on5kEMPaHFpMPf_6WtQgrQK_6ZtKzlb2Wu0aAkWKEALw_wcB&gclsrc=aw.ds. [Accessed 1 12 2018].

[3] Ratchet Straps USA, "2" Endless Loop Ratchet Strap," [Online]. Available: https://www.ratchetstraps.com/2-endless-loop-ratchet-strap. [Accessed 28 November 2018].

[4] Acklands Grainger, "CLAMP, ONE-HANDED,FAST ACTION, 6IN," [Online]. Available: https://www.acklandsgrainger.com/en/product/p/BESEZS15-8?gclid=Cj0KCQiA2o_fBRC8ARIsAIOyQ-n3SnA3UAxvpllm4wOvfyOE9xQCHJplYZjL8nhqQde-aAXLDz7MxlcaAlqbEALw_wcB&cm_mmc=PPC:+Google+PLA&ef_id=Cj0KCQiA2o_fBRC8ARIsAIOyQ-n3SnA3UAxvpllm4wOvfyOE9xQCHJplYZjL8nhqQde-aA. [Accessed 1 December 2018].

[5] Princess Auto, "6 in. Quick Release Aluminum Bar Clamp/Spreader," [Online]. Available: https://www.princessauto.com/en/detail/6-in-quick-release-aluminum-bar-clamp-spreader/A-p8344269e;jsessionid=2qKJ-zazQsrqTSnwGYUcKSDW.pal-prod-com2. [Accessed 1 December 2018].

[6] "ACKLANDS GRAINGER," [Online]. Available: https://www.acklandsgrainger.com/en/product/NEO-POT-BOLT-MGNT-2-62D-X-0-37/p/ECLE688. [Accessed 22 November 2018].

[7] "K&J Magnetics, Inc," [Online]. Available: https://www.kjmagnetics.com/proddetail.asp?prod=D9C. [Accessed 3 December 2018].

Appendix H – Preliminary Engineering Drawings

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Below are preliminary engineering drawings for the final design. Figure 1 shows the full assembly drawing for the cover with all associated components and locations. Figure 2 shows the drawing for just the cover and shows dimensions for all features of the cover.

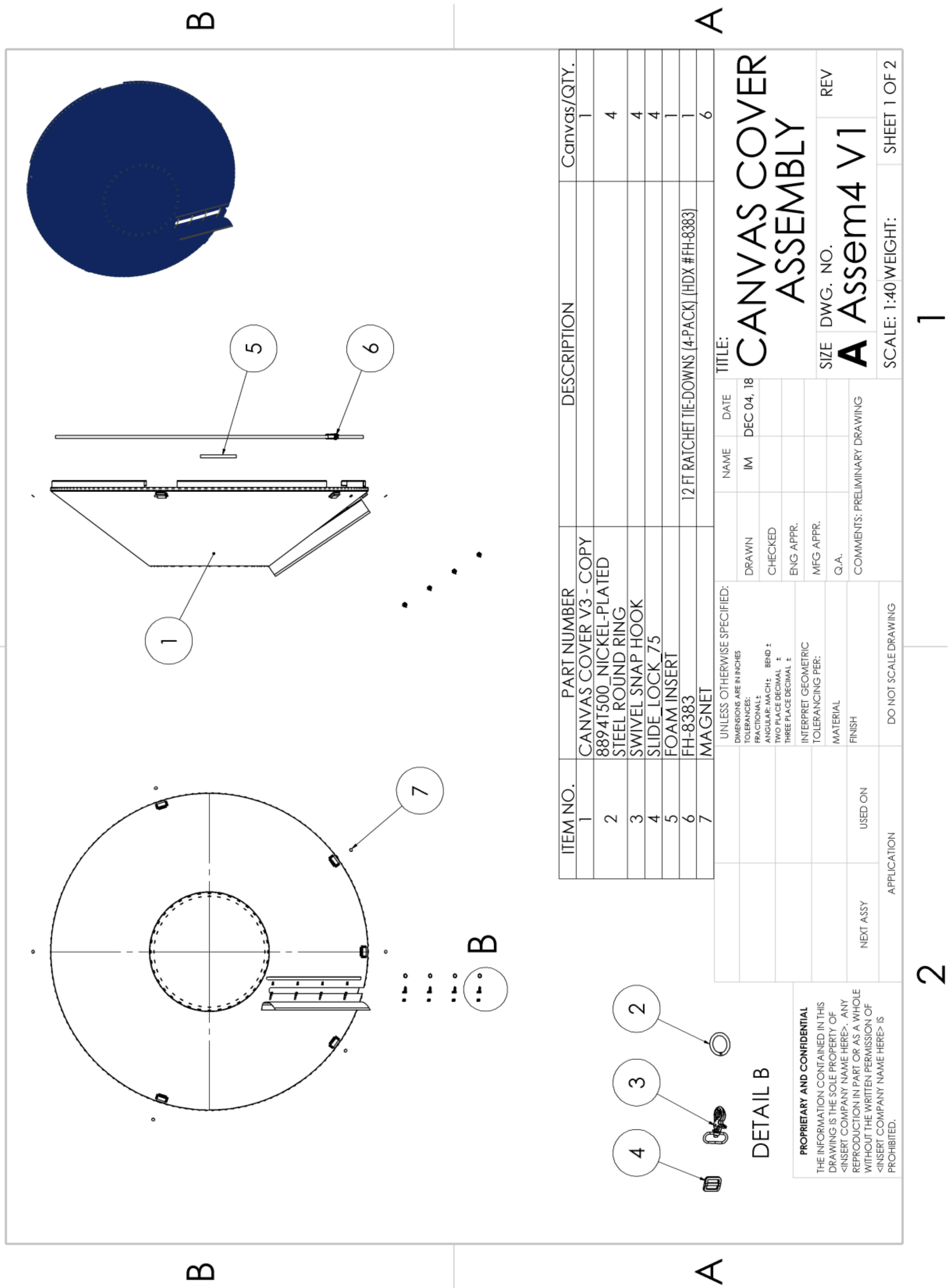


Figure 1. Full Cover Assembly Drawing

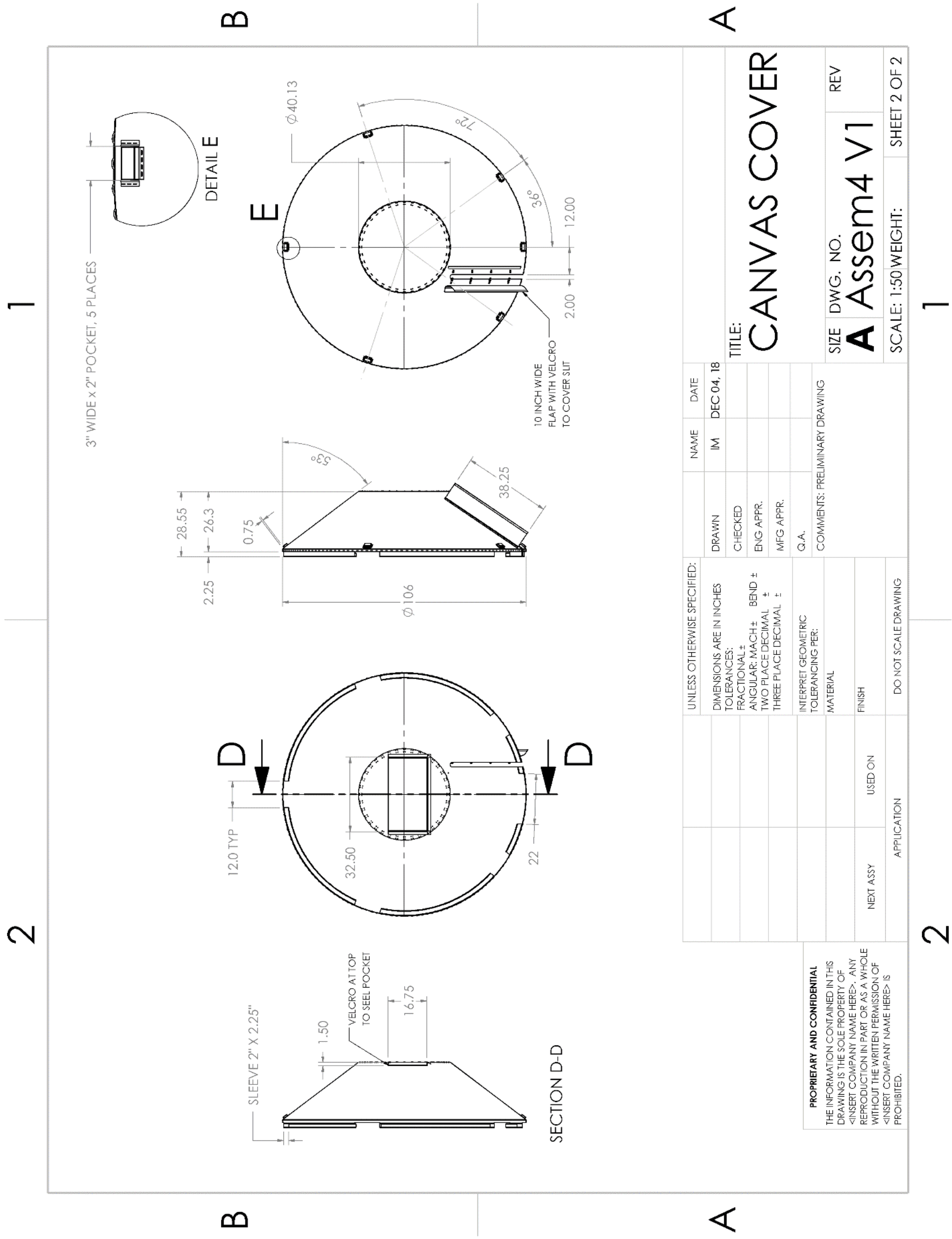


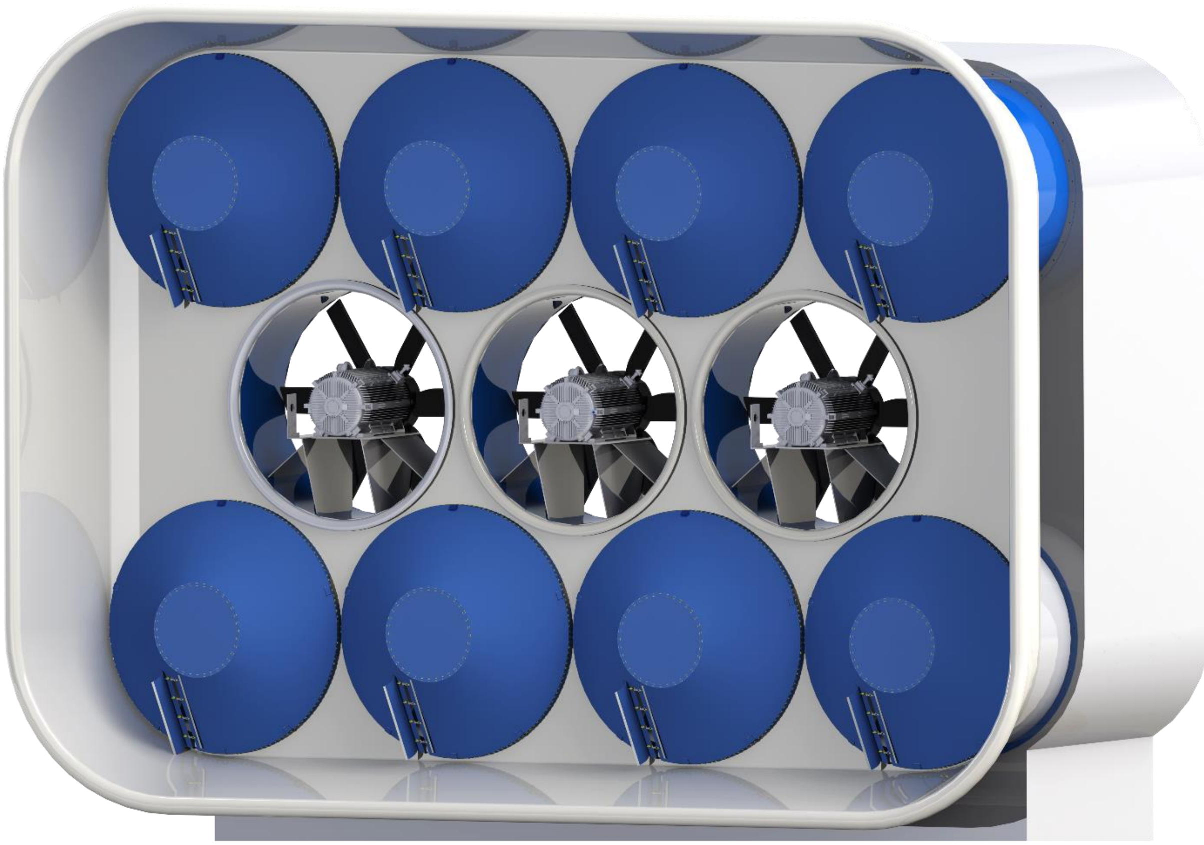
Figure 2. Cover with Features Drawing

General Electric Fan Inlet Cover

INSTALLATION MANUAL

Introduction

The fan inlet cover is a highly efficient cover to go on each fan inlet of the wind tunnel at the GE TRDC. The covers protect the wind tunnel by minimizing the wind and debris entering the tunnel and prevents fans from windmilling when not in use. This aids in safety when pipes and nozzles are being serviced inside the tunnel and allows for a higher quality of working conditions.



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HANDLING PRECAUTIONS

Read these handling precautions to ensure correct installation of the fan covers. To maintain safe working conditions, deviations from precautions should be avoided unless in emergency situations.

- Only install one fan cover at a time.
- Ensure to install covers with at least 2 people.
- Remove all debris prior to installation. This ensures adequate performance of the covers.
- Complete a thorough inspection prior to installation to ensure components are in good working condition.
- Ensure sleeves are inserted behind lip before tightening ratchet straps.
- Do not put hands between magnet and wind tunnel when initially placing cover over inlet.
- Do not install when wind speeds are greater than 40 km/h. Operationally the Skyjack can withstand 48 km/h.
- Do not install when temperatures are outside -40°C to 40°C. Avoid installation in other inclement weather conditions
- Immediately replace components that appear to be damaged or broken.
- Do not leave fan covers outside when not in use. Store away properly indoors.

ITEM CHECKLIST

Prior to installation, check that the following items and equipment are available for use. If any of the components are damaged, replace prior to installing covers. The following list of items required pertains to covering a single inlet.

Item	Quantity
Fan Inlet Cover	**1**
Ratchet	**1**
Bar clamps	**3***
Polyfoam Block	**1**
Skyjack SJ66T	**1**
Magnets	**6**

*** Total of three required. The same three bar clamps can be used for the installation of each cover.**

COVER INSTALLATION

The following set of instructions outlines the individual steps for the installation and uninstallation of a single cover. Steps can be repeated for each individual cover, or technicians may devise a way to transport multiple covers at their discretion to reduce installation time.

Setup

1. **INSPECTION:**
    a. Check to make sure foam inserts and magnets are intact and secure inside pocket.

    b. Check to make sure all covers are folded in the same orientation and bar clamps are secured.

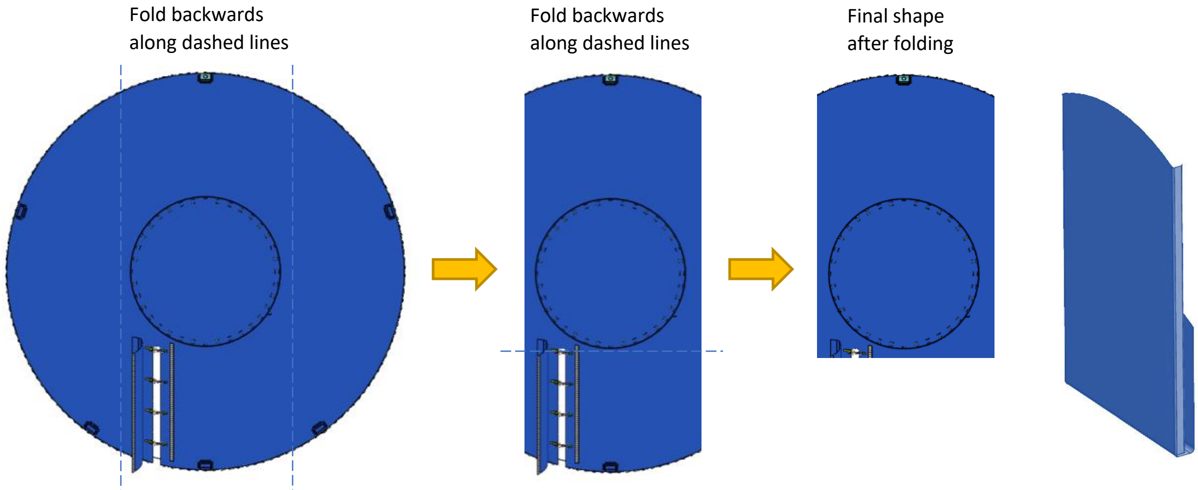
    c. Ensure adequate amount of fuel available in the Skyjack SJ66T lift.

2. **PREPARATION:** Remove the covers from storage and transport to the wind tunnel.

3. **EQUIPMENT:** Have the Skyjack SJ66T ready for use and in position in front of the wind tunnel.

Installation

1. **ATTACH:**
    a. Clamp the covers to hold the folds in place. This will allow the covers to remain folded when installing.

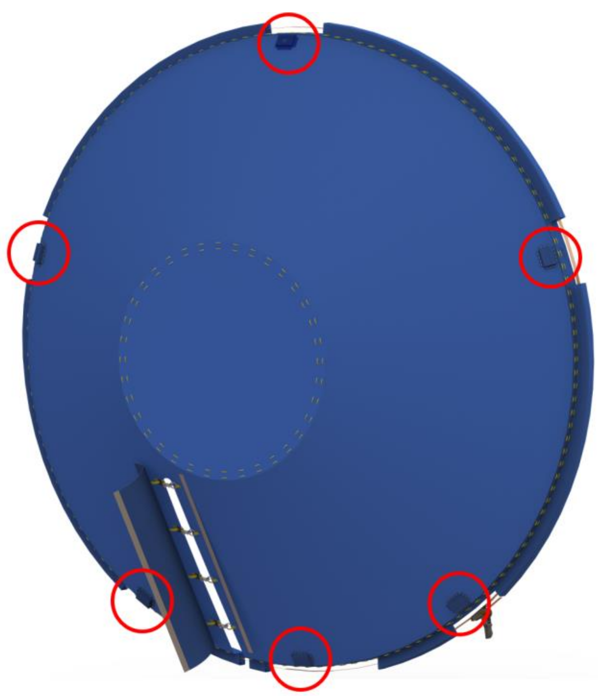


b. Tack cover to the fan inlet with the top magnet to hold the cover in place.

c. Clamp the top of the cover to the fan inlet using a bar clamp. Tuck in top sleeve behind fan inlet lip.

d. Remove bar clamp from one side of the cover (either left or right side).

e. Unfold unclipped side. Tack cover to the lip using the magnets and clip with bar clamp to hold in place. Ensure sleeves are tucked in behind the lip.

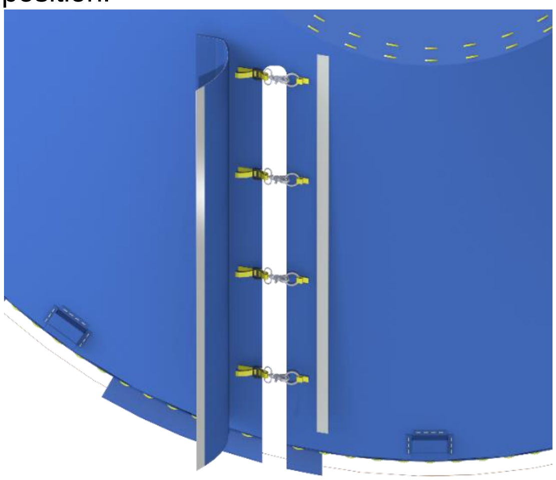


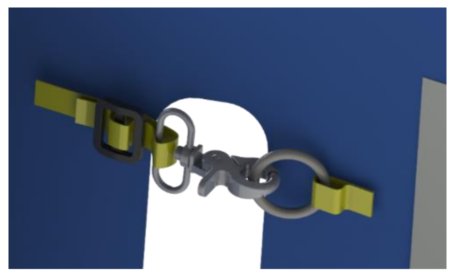
f. Repeat steps 1d. and 1e. for opposite side of cover.

2. **SECURE:**
   a. Feed strap through ratchet and tighten partially.

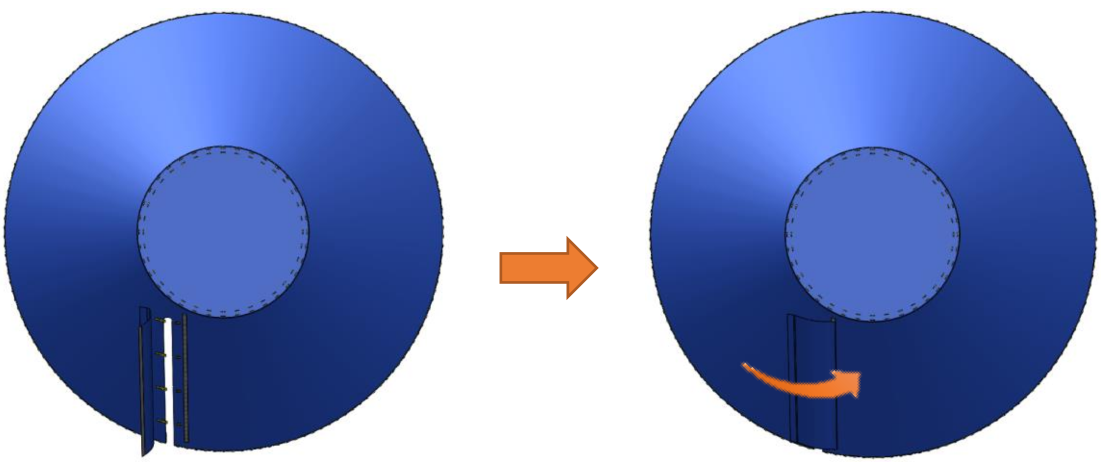
   b. Remove all bar clamps from fan inlet and place inside Skyjack.

3. **CLOSE:**
   a. Join both halves of the cover behind the cable by attaching all four D-rings to the associated spring snaps. Use the adjustable straps to slide the spring snaps in position.



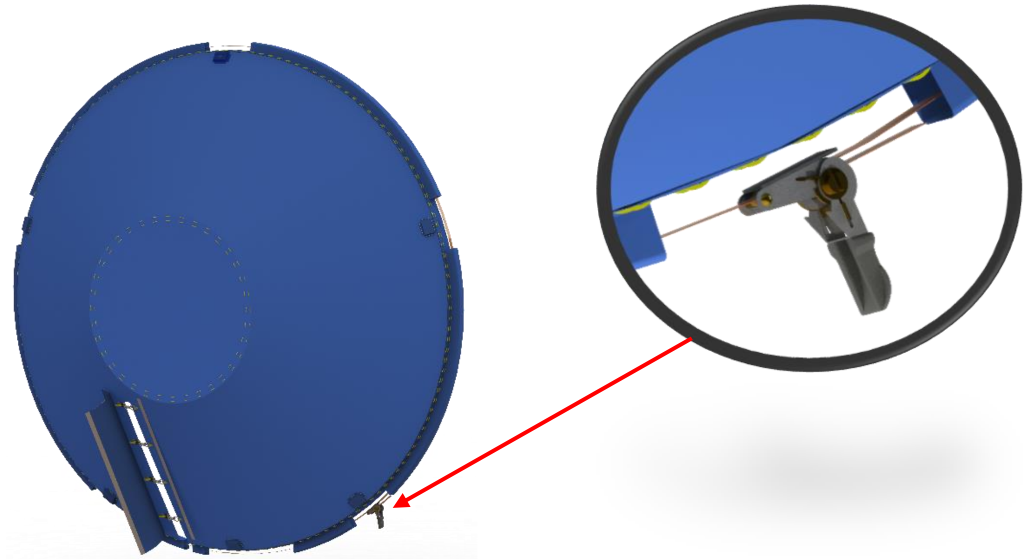


   b. Use Velcro flap to cover over D-rings.



4. **TIGHTEN:**
   a. Ensure cover is aligned properly. The pocket for the foam insert should be in front of the motor.

b. Tighten ratchet strap until cover is taut. Ratchet should be tightened on lower right corner of each inlet.*



***Inlet in the lower right corner of wind tunnel should have ratchet tightened on lower left side of the cover.**

Uninstallation

1. **UNLATCH:**
   - **a.** Undo Velcro and unclip D-rings to separate both halves of the cover.
   - **b.** Loosen ratchet to remove tension from covers.
2. **REMOVE:**
   - **a.** Remove bottom half of cover by lifting off magnets. Place the bottom half of the cover into the basket.
   - **b.** Raise lift and remove sleeves out from behind lip until fully removed at the top.

Storage

1. **CLEAN:**
   - **a.** Clean off any dirt or debris on the cover with a pressure washer and water.
   - **b.** Let covers dry off or manually dry off to prevent the growth of mold or mildew.
2. **FOLD UP:**

- **a.** Fold the bottom part of the covers up
- **b.** Fold in both halves of the cover so that they meet in the middle
- **c.** Use bar clamps to hold the folds in place. Ensure one clamp is on either side of the cable slit

3. **STORE AWAY:** Put covers away for storage when not in use. Keep covers inside.

COVER INSTALLATION TIME

The design for the fan inlet covers allow for quick installation and assembly. TABLE I below shows an estimated breakdown to install one cover.

TABLE I INSTALLATION TIME BREAKDOWN

Step	Time	Notes
Installation		
Attach	4 mins	This includes steps to attach the fan cover from unfolding the cover to getting the cover tacked on with the magnets and clipped with the bar clamps.
Secure	1 min	Feed the strap through the ratchet and tighten partially and removing the bar clamps.
Close	1 min	Attaching the D-rings to the spring snaps and closing the Velcro flap
Tighten	1 min	Tightening the ratchet to hold the cover onto the wind tunnel and ensuring proper alignment.
Total	7 mins	

Each cover takes approximately 7 minutes to install from the time the technicians are standing in the lift to when the cover is secured and standalone on the fan inlet. Adding a one minute buffer time between cover installs, the total installation time for eleven covers is 87 minutes.

The uninstallation process time and details are shown in TABLE II.

TABLE II UNINSTALLATION TIME BREAKDOWN

Step	Time	Notes
Uninstallation		
Unlatch	2 mins	Undoing the spring snaps from the D-rings and loosening the ratchet strap to relieve tension.
Remove	1 min	Lifting off magnets and removing cover from the fan inlet into basket.
Total	3 mins	

The uninstallation process is quicker than the installation process since the cover can easily come off and fall into the basket of the Skyjack. The uninstallation time per cover is estimated to be 3 minutes. Adding a one minute buffer time between each cover, the total uninstallation time to for all eleven covers is estimated to be 43 minutes.

It is estimated that getting hooked up into safety harnesses and getting all equipment to the wind tunnel takes approximately 30 minutes. This brings the total installation time for all covers to be 117 minutes, and the total uninstallation time to be 73 minutes. TABLE III summarizes the breakdown for total installation and uninstallation time for all covers on the wind tunnel.

TABLE III TOTAL TIME FOR INSTALLATION AND UNINSTALLATION

Procedure	Installation Stage	Time [mins]	Total Time [mins]
Installation	Setup	30	117
	Cover install	77	
	Buffer	10	
Uninstallation	Setup	30	73
	Cover uninstall	33	
	Buffer	10	

Not included in the time for installation and uninstallation is the time to clean the covers. The time is highly dependent on environmental conditions and how much debris accumulates onto the covers. Removing and placing the covers from storage and preparation time can vary and have not been included in the installation time.